International Journal of Agriculture and Forestry 2014, 4(6): 459-464
DOI: 10.5923/j.ijaf.20140406.07

A Development Perspective to Tree Resource Domestication in Agriculture

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Abstract Tree Resource Domestication (TRD) is recognised as a complex biological process but its value in the development of agriculture is yet to be substantially explored. The study makes use of tree utilization and conservation as an introduction to the concept of TRD that is built around ecosystems and genetics. A desire to use tree products on a sustainable level initiates the transfer of trees from their natural habitat to artificial environments. Tree resource growing in controlled environments exhibits profound changes in morphology and physiology leading to compact growth and higher productivity. These improvements in the biology of trees represent at the same time different Levels of Tree Development. Domestication as both ecological adaptation of trees to agricultural ecosystems and their genetic improvement provide clues into a development pattern in agriculture. These insights inform the proposal concerning Tree Resource Domestication in the development of agriculture.

Keywords Human-tree interaction, Selection, Tree crops

1. Introduction

Tree Resource Domestication is closely linked to the development of silviculture, horticulture and tree crop agriculture. It explains the origin of certain differences in production traits of wild trees and their cultivated counterparts [1-6]. Domestication is also credited with the emergence of consistent fruiting pattern and higher productivity in native trees as in the case of the African oil palm (*Elaeis guineensis*), African bush mango (*Irvingia gabonensis*) and African plum (*Dacryodes edulis*) [7-9]. But most importantly, the domestication of trees is believed to be the pathway towards sustainable production of major forest products [10-12]. Conversely, the sustainability engendered by the domestication of trees is at the same time facilitating the demise of industries that thrives on the exploitation of natural forests.

A number of studies on the different aspects of Tree Resource Domestication abound. Some of such investigations emphases the conservation of tree genetic resource in natural habitats [13, 14], the bio-geographical origin of the wild progenitors of tree crops and the genetics of their evolution [15-18]. In other words, these investigations pay less attention to the domestication of trees as a development process within the institution of agriculture.

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Published online at http://journal.sapub.org/ijaf

There is therefore a need to examine Tree Resource Domestication in relation to the development of agriculture. Such an examination is likely to prove valuable in the search for new models of development concerning agriculture. For this reason, a review of relevant literatures on the subject matter including those that make reference to it has been undertaken. The study basically explores the concept of Tree Resource Domestication (TRD) with the aim of situating it within the development of agriculture.

2. Tree Resource Domestication (TRD): An Overview

The knowledge of "forest", its utilization and conservation are vital to the domestication of trees. Forest is either defined in terms of specific criteria that includes the size of land area with tree crown (0.5 hectares) and minimum height of trees at maturity (5meters) or described in general terms as a landscape of trees and other associated woody plants [19, 20]. More still, forests constitute broad ecological zones within which valuable tree species grow as pioneer vegetations. Some of the notable trees that thrive as native population are the wild olive tree (*Olea oleaster*) occupying the eastern shores of the Mediterranean sea [15] and the wild pecan (*Carya illinoiensis*) that flourish in forests of North America [21]. Trees as species localized to certain region is also made evident by African bush mango (*Irvingia gabonensis*) growing in the rainforest of sub-Saharan Africa [22] and wild macadamia (*Macadamia ternifolia)* which is endemic to the rain forest of Australia [23]. Natural populations of several other species of trees are indigenous to Africa.

Among the most common tree flora of Africa are the African oil palm (*Elaies guineensis)*, African bush mango (*Irvingia gabonensis*), African plum (*Dacryodes edulis*), the Shea *(Vitellaria paradoxa)*, species of mangrove (*Rhizophora*) and raffia palm (*Raphia)*. Some of the food-bearing trees and their wood counterparts have been appreciated as valuable plants by indigenous people since ancient times leading to their continuous exploitation.

The utilization of non-wood tree products is becoming more prominent in different regions of the world. Tree parts are now important sources of food, vegetable oils, fibre, latex and other products for both forest-dependent communities and industries [24]. However, the challenges resulting from the continuous exploitation of natural tree products necessitate the preservation of natural populations, maintenance of conditions for genetic evolution and a reduction in the rate of forest genetic erosion [13]. The preferred choice for achieving conservation goals for tree species in natural ecosystems is the *in-situ* strategy while the *ex-situ* strategy remains valuable for establishing artificial ecosystems. Conservation of wild population of *Coffee arabica* in the montane rainforest in Ethiopia and the conservation of native fruit trees in Asia are recognised by the International Treaty on Plant Genetic Resource for Food and Agriculture (ITPGRFA) as major *in-situ* conservation projects. Similarly, botanical gardens, field gene banks and seed gene banks including the Millennium Seed Bank Project of the Royal Botanical Gardens, Kew are all acknowledged by ITPGRFA as *ex-situ* conservation projects.

Domestication of trees from conserved natural population is driven primarily by the desire to use tree genetic resources in a sustainable manner. Tree Resource Domestication may be categorised into an initial, intermediate or final phase [1, 25]. However, fundamental changes to the bio-physical environment and improvement of genes are inherent in the different phases of domestication [26].

TRD as Ecosystem Change.

The mode of domestication in the earliest tree domesticates remains a subject of speculation. Yet, it is most probable that ancient domesticates were monitored and preserved within natural forests prior to their transfer to artificial ecosystems [1, 25]. In some cases, seeds or seedlings of trees were also transported from their native range to other continents as witnessed during the Age of Discovery or the period of European global exploration. Such transfers that change the ecosystem of trees have been an integral part of Tree Resource Domestication. The processes that lead to the domestication of rubber (*Hevea braziliensis*) typify the role of *Ecosystem Change* in transforming trees from natural forests into crops that are adapted to agricultural ecosystems. Rubber grows naturally in the Amazonian rainforest but all that changed after 1876 when rubber seeds were collected and later transported to England [27]. The few seeds that germinated out of the several planted were later transported to SE Asia. Today, the presence of extensive rubber plantations in different parts of the world could be traced to generations of those young trees that were supplied from England to SE Asia [27].

TRD as Genetic Improvement.

Wild trees experience “genetic change” in the course of successive growth and development in human-controlled conditions. The wild apple *(Malus. sieversii*) may have undergone series of gene duplication leading to the emergence of the domestic apple (*Malus domestica*) [17]. The evolution of distinct genetic structure in cultivated trees affects the expression of certain traits making them superior to their wild relatives. A good example of the contribution of “genetic change” to phenotypic differences in traits under selection and during domestication is the development of fruit characteristics in apples [17, 28]. A similar event defines the genetic relationship between cultivated grape (*Vitis vinifera*) and its wild relative *Vitis sylvestris* [18]. The domestication process has also been improved significantly through plant breeding as demonstrated in breeding programmes involving oil palms. Thick-shelled homozygote deli dura population in a monohybrid cross with the best of shell-less pisifera population produce a heterozygote tenera with a thin shell [29]. The inheritance pattern that lead to a reduction in shell thickness in the hybrid tenera population facilitated increases in mesocarp size as well as oil yield. Furthermore, the tenera fruit type which is heterozygous for shell thickness may be said to be genetically superior to the thick-shelled deli dura that is homozygous for the same trait. The tenera fruit type of oil palm, like cultivated apple and grape, affirms the fact that domestication also involves the improvement of genes.

3. TRD: The Development of Crops

A number of trees have been developed into crops through the domestication event. Olive tree of the Mediterranean region, rubber tree of the Amazonian rainforest and macadamia tree of Australia have all been transformed into crops. Trees that are indigenous to Africa have also experienced the transforming-effect of domestication. One of such trees is oil palm (*Elaies guineensis*) whose success is perhaps the motivation behind on-going domestication effort directed at other trees like the African bush mango (*Irvingia gabonensis*) and the African plum (*Dacryodes edulis*).

The oil palm is of the plant family *Palmae*, genus *Elaeis* and scientifically referred to as *Elaeis guineensis*. It grows only in the African rainforest prior to its domestication [30, 31]. Oil palm produces fruits with a mesocarp that bears red oil; an important food ingredient in the diet of indigenous people of West Africa. The first attempt at domesticating oil palm dates back several hundreds of years when trees that were preserved on farmlands progressively flourish into semi-wild grooves [25, 30, 31]. These semi-wild palm grooves supplied the entire palm oil and kernels that were traded between West Africa and Europe.

Domestication of oil palm in modern history began with the transfer of seedlings out of its native continent. In 1848, some oil palm seedlings were transported from West Africa to Southeast (SE) Asia where they were planted in the Botanic Garden of Bogor, Indonesia [30, 31]. The young oil palm seedlings express faster growth rate in their new habitats that has a relatively higher rainfall and longer photoperiods. In addition to fast growth, the yield of the newly introduced tree doubled due to partitioning of more resources for the production of fruit bunch [10, 32]. This yield-enhancing effect of optimal climatic conditions on oil palm is further enhanced by the absence of major pest and diseases which are common environmental challenges in West Africa. All these factors- optimal climatic conditions and disease-free habitat- are contributory factors to the establishment of the oil palm industry from generations of those oil palm seedlings earlier transported from West Africa.

Plantation-grown oil palms that were selected for yield produced progenies with higher productivity. Generations of plantation-grown oil palms have production capacity that exceeded those of their parents by more than 50 percent [7, 31]. More still, hybrids of oil palms obtained from plant breeding programme, as previously explained, resulted in oil yield that is one-fifth higher the previous production values. The higher-yielding 'tenera' fruit type is the main planting materials in the development of major oil palm projects. As a result, plantation-grown oil palm now accounts for almost 100 percent of palm oil traded on the international market thereby replacing semi-wild palm grooves as the major source of the product [7, 31].

The West African forest tree referred to as oil palm is now a crop of global importance as a result of the domestication event. Less than a century after the success story of oil palm domestication, attempts at transforming the African bush mango and the African plum into crops are in advanced stages. Through such attempts, the Bush mango and the Plum which are restricted to Africa are on their way to becoming agricultural crops that may be grown in other continents. These trees- the Bush mango and Plum- share certain similarities as potential tree crops. For this reason, the account of domestication for one of the trees would suffice.

African bush mango belongs to the family *Irvingiaceae*, genus *irvingia* and exists as two known species: *Irvingia gabonensis* (Aubry-Lecomte ex O'Rorke) Baillon and *Irvingia wombolu (*Vermoesen) [22]. Both species which are found growing in the humid lowland forest of Africa bear edible fruits [8, 33].

The *irvingia* tree as a valuable food resource is preserved on farmland during land preparation. In such a situation, protected bush mango trees progressively flourish as their growth and development proceeds without interference from *Competitors*. It is an expectation of farmers that bush mango be cultivated even though transplant of wild seedlings onto farmland is becoming a common cultural practice [34-37]. The adoption of bush mango domestication programme facilitated the systematic collection of germplasm from its centre of diversity as well as encouraged the search for vegetative propagation methods. Seedlings of bush mango obtained through vegetative propagation techniques have been employed in establishing nurseries and field banks [38, 39]. Trees of the bush mango which grow well over a decade in their natural habitat before fruit production attains maturity 4 to 5 years in well managed environment [8, 33]. These reductions in maturation suggest that the tree is responding to human selection. The suggestion that genotypes with superior production traits exit within the population of field-grown bush mango further encourage the selection of high yielding trees.

4. A Development Perspective to TRD in Agriculture

The importance of domesticating trees of wild origin is made evident in the development of silvicultural and horticultural crops.

Domestication alters growth pattern in wild trees. The growth pattern of trees which marks them as a distinct category of plants is subject to the influence of wide range of environmental factors [40, 41]. In this situation, trees often manifest prolonged growth period as indicated by its extended juvenility and age at maturity. Nevertheless, the growth pattern in wild trees has been modified through series of selection and genetic improvement activities [11, 12, 38, 39]. Through these media, domestication reduces the age at maturity of wild trees and fosters a compact growth habit. For instance, some wild macadamia trees (*Macadamia ternifolia* F. Muell) require at least 20 years of growth preparatory to the production of fruits. But a 1-2 year nursery grown seedlings of the macadamia that were transferred to a field attain reproductive maturity 4-6 years after transplantation [23].

Domestication also regularises the fruiting and flowering patterns in wild trees. Generally, wild trees devise strategies for balancing vegetative and generative growth at maturity as indicated by their inconsistent and extremely cyclic fruiting pattern [42, 43]. Many wild trees alternate their reproductive years in order to replenish nutrients that were used up during reproductive growth while a few exhibit regular flowering pattern [40, 41]. The regularization-effects of domestication on flowering pattern are evident in a number of recently domesticated trees such as the pecan (*Carya illinoiensis*) and the macadamia (*Macadamia ternifolia*). Domesticated pecan manifests strong alternate-bearing habit which is an improvement on the behaviour in wild pecan [21]. More still, the alternate flowering habit of cultivated pecan is improved further to a fairly consistent pattern using advances in horticulture management. In situation similar to that of the pecan, domestication has normalized the flowering pattern of the macadamia tree. Selection efforts have gradually transformed the fruiting pattern of macadamia tree from its usual irregular pattern to a fairly regular one [23].

Domestication, through the combined effect of growth alteration and fruiting pattern regularization, transforms the productivity of many trees. In nature, the full expression of the productive capacity of a tree is not often realized as a direct consequence of interference by suboptimal climatic conditions and biotic stress [41]. This restriction when surmounted through the process of domestication allows more dry matter to be partitioned for generative growth thereby increasing tree productivity [11, 32]. The impact of domestication on tree productivity could be appreciated by comparing the production values of the earliest plantings of rubber and those of modern plantations. The productivity of rubber in natural forest may have been less than 450 pounds per acre per year as this estimate represents the yield of its earliest plantings but modern clones of rubber produce over 3500 pounds per acre per year [27]. Similarly, the productivity of oil palm progressively increase with advances in selection and plant breeding techniques [7, 31].

From the fore-going discussion, the development of tree domesticates is at the same time a transformation in *development levels* of wild trees. Generally, wild trees may be categorised into groups using their contributory value to food and agriculture. Based on the "utility" criterion, wild trees such as the African bush mango (*Irvingia gabonensis*), African plum (*Dacryodes edulis*), and the African oil palm (*Elaies guineensis*) could be termed Food-Bearing Trees; rubber (*Hevea braziliensis*) and species of raffia palm (*Raphia*) as Latex/Fibre Producing Trees and species of mangrove (*Rhizophora*) as Less-Valued Trees. Species of trees in any of the category are at the primitive state or *Primary Level of Tree Development* and may simply be referred to as a *tree*. Some *trees* appeal to the appetite of the indigenous human population initiating a *Tree Evaluation Exercise* (TEE) in the process. A successful TEE that confirms a *tree* as valuable for either dietary or non-food purpose facilitates its exploitation. Preference for trees based on TEE often lead to the establishment of Protected Areas/Forest Reserves or to their preservation on farmlands within forest area [1, 25]. Again, the outcome of *Tree Evaluation Exercise* (TEE) promotes the exploitation of Food-Bearing Trees as well as Latex/Fibre Producing Trees but not Less-Valued Trees. With the commencement of exploitation, a *tree* is valued not just as a *tree* but a *tree resource*, that is, *tree of direct value to humans*. From a development perspective, such exploitable *trees* have evolved from the primitive state or *Primary Level of Tree Development* to an intermediate state or *Secondary Level of Tree Development*. For instance, the mangrove, raffia, rubber, bush mango, plum and oil palm are all *trees* growing in ecological zones within the tropics. However, the discovery of the food value of the bush mango, plum and oil palm as well as the relevance of raffia fibre and rubber latex as raw materials elevates them to the *Secondary Level of Tree Development* while the species of mangrove which are comparative of less value exist as mere *tree and* remains at the primitive state or *Primary Level of Tree Development*.

A *tree resource* is developed further by a transfer from its natural habitat to human-controlled environment. In agricultural ecosystems, a tree at the intermediate state undergoes series of morphological and genetic changes as a result of selective pressures inherent in the domestication process. Interestingly, these changes which are improvements in productivity are at the same time a transformation in the *development level* of cultivated trees. Stated alternatively, a *tree resource* progress to becoming a *tree crop* under the influence of domestication without which it remains a *tree resource*. *Tree resource* as a category for "utility trees" includes among other trees the raffia, rubber, bush mango, plum and oil palm. Bush mango, plum and oil palm as *tree resource* are important food ingredients in the diets of indigenous peoples while raffia palm and rubber are valued for non-food purposes. The continuous collection of other *tree resource* like the bush mango, plum and raffia palm from natural forests keeps them at intermediate state or *Secondary Level of Tree Development*. However, the recent transfer of the bush mango and plum to agricultural ecosystems sets them at the threshold of a new *Level of Tree Development*. Other *tree resource* such as oil palm and rubber whose transition to agricultural ecosystems were initiated much earlier and have been completely domesticated are no longer *tree resource* but *tree crops*. Put differently, a *tree resource* that have been completely domesticated have attained the most advanced state or *Tertiary Level of Tree Development*.

The main theme of the study may be summarised as follows: domestication of trees as a biological process involves the transformation of mere *trees* through *tree resource* to *tree crops*. The phases-*trees, tree resource, tree crops*- within Tree Resource Domestication represents *Primary, Secondary, and Tertiary Levels of Tree Development*. These different *development levels* in trees characterise the establishment of silviculture and horticulture as aspects of agriculture.

5. Conclusions

An investigation into Tree Resource Domestication, its most recent successes and on-going attempts has been undertaken. The effects of domestication on trees prompt the following deductions:

- Tree Resource Domestication is a human-tree interaction that has evolved into a platform on which *trees* transit into *tree crops* thereby highlighting the magnificence of the human "agriculture genius".
- Tree Resource Domestication as a transformational platform to which all modern *tree crops* owe their existence is a fundamental structure in the development of plantation and tree crop agriculture.
- Tree Resource Domestication as a fundamental structure in the development of certain sectors of agriculture suggests the existence of a development architecture within agriculture.

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