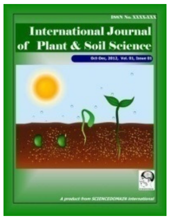

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Climate Change and the Fate of Genetic Diversity of Crop Wild Relative Species

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Author's contribution

The sole author designed, analyzed and interpreted and prepared the manuscript.

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ABSTRACT

Plant species are experiencing increasing challenges from climate change. Climate change is a serious threat to plant genetic diversity and the survival of many plant species which may substantially alter biodiversity. Crop wild relatives contribute many valuable genes for improvement of crops and being more resilient with the impact of climate change. Do these useful genetic traits from crop wild relatives make them safe from the impact for climate change on their genetic diversity? In this paper, the impact of climate change on crop wild relatives and how the impact will affect the genetic diversity of the species is discussed with focus on factors influencing the genetic diversity. Climate change is expected to cause changes in flowering phenology, plant-polinators interactions, seed dispersal and soil seed bank, the factors which influence the genetic reservoir, genetic composition and frequencies of alleles present in the population. Furthermore, the paper discussed how the climate change may play a direct role in promoting invasive plant species and potential for influencing a range of many plant pests and diseases which will profoundly affect the genetic diversity of plant populations. The consequences of loss of plant genetic diversity was also discussed which includes species being at risk of extinction. Finally, the paper highlighted *in situ* and *ex-situ* as important conservation and mitigation measures needed to preserve the genetic diversity of wild plant species.

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1. INTRODUCTION

The world's climate is changing at an extraordinary rate and this change will continue over the subsequent decades [1]. Plant species play important roles in providing habitat, food or mutualisms with many animals, fungi, micro-organisms and other plants in addition to other ecosystem services as well as resources for human use. A crop wild relative is a wild plant taxon that is closely related to a domesticated plant or has an indirect use derived from its relatively close genetic relationship to a crop [2]. Being more or less genetically related to crops, the crop wild relatives have contributed many valuable genes to crop plants which have improved the quality and yield of many varieties of most major crops including food, fodder and forage crops, ornamental, medicinal plants, forestry species, as well as plants used for industrial purposes [3,4,5]. Furthermore, genes from crop wild relatives have provided cultivars with resistance against pests and diseases and enhanced tolerance to abiotic stresses [6,7].

The potential usefulness of crop wild relatives in agriculture is due to presence of genetic traits being more resilient for the impact of climate change. These genetic traits allow the species to cope with a wider range of environments and stresses resulting from the climate change [8,9,10,11]. However, with such enormous promises for adapting agricultural crops to climate change, are the crop wild relatives themselves safe from the impact of climate change? This paper discusses how the crop wild relatives like other wild plant species will be affected by climate change thus posing a threat not only to their survival but also to the loss of their genetic diversity.

The genetic diversity crop wild relative species is rarely considered in the literature on its fate in the potential future climate change. While a broad range of studies has reported generic impacts of climate change on plant biodiversity and ecological consequences [12,13]. There is limited information on the effect of climate change genetic diversity of crop wild relatives. Climate change will provide some species the opportunity to expand their range while others may experience a reduction in their potential range [14,15]. Focusing on crop wild relative, the study by Thomas et al. [16] based on a cross section of about 1100 wild plant species, predicted that 15–37% were in danger of extinction due to climate change. Some more studies have envisaged increasingly severe future impacts of climate change with potentially high extinction rates in natural systems around the world [17,18].

The knowledge on how the climate changes affect the genetic diversity of plant species is very important not only for species' persistence and evolutionary potential, but also for community structure and ecosystem flexibility [19,20,21]. Currently, the International Union for Conservation of Nature [10] red list criteria do not take genetic diversity into account. However, with the current scenario of climate change, plant species with a population decline and genetic diversity loss is expected in the future. The consequences of loss of genetic diversity as a result of climate change may be expected to affect all levels of biodiversity including the crop wild relatives [22,23].

In this paper, conceivable impact of climate change on factors influencing the genetic diversity of plants is discussed focusing on crop wild relative species in tropical Africa. Although tropical crop wild relatives are naturally adapted to warmer climates, but climate change will cause further increases in temperature that will adversely affect biodiversity of plant species. Some examples of important plant families with important crop wild relatives found in tropical Africa include; the family Rubiaceae with species *Coffea pocsii* Bridson and *Coffea sessiliflora* Bridson used as source of gene pool for *Coffea arabica* L. Other family is Cucurbitaceae with the following crop wild relatives *Cucumis pustulatus* Hook. f. and *Cucumis pustulatus* Hook. f. as source of gene pool for *Cucumis melo L.* and *Cucumis sativus* L. From the family Poaceae the following crop wild relatives *Eleusine jaegeri* Pilger, *Eleusine multiflora* Hochst. ex A. Rich and *Eleusine africana* K. OByrne used as the source of gene pool for *Eleusine coracana* (L.) Gaertn. The family Poaceae also contains *Sorghum virgatum* (Hack.) Stapf, a crop wild relative used in breeding for *Sorghum bicolor* (L.) Moench. From the family Solanaceae, crop wild relatives namely *Solanum cyaneopurpureum* De Wild, *Solanum anguivi* Lam and *Solanum mauense* Bitter are used as gene pool for *Solanum melongena* L. [24,25].

Genetic diversity is the most important form of biodiversity, and consequently is one way to get an overall better view of how species are affected by climate change. The genetic diversity for crop wild relative species receives less attention and management interventions compared to the genetic diversity for crop plants used in agriculture when related to issues of climate change. Moreover, wild plant species need consideration since it is from these plants the crop wild relatives are obtained being used as an important source of genetic diversity for crop improvement [11,26].Furthermore, the paper highlights on important conservation and mitigation measures needed on wild plant genetic diversity for the long-time survival of species.

2. INFLUENTIAL FACTORS FOR PLANTS GENETIC DIVERSITY AND POTENTIAL IMPACTS OF CLIMATE CHANGE

2.1 The Reproductive System through Phenology

Phenology is a periodic plant life cycle event that includes the date of emergence of leaves and flowers, and how these are influenced by seasonal and inter annual variations in climate. Plant phenology is a reproductive system in plants that significantly determines the genetic structure of plant populations as well as the effects of selection, genetic drift, and migration; it is also an important component of a species' capacity to colonize new environments [27]. The timing of phenological events such as flowering is often related to environmental variables such as temperature. Climate change is thus expected to lead to changes in life cycle events, such as unusual early flowering; range shifts due to changing weather patterns have been reported in many species of plants [28,29]. Some plants whose phenology has been affected by climate change include *Mertensia ciliata* whose populations already reported to be severely declining in their range [30]. Other studies also report that climate change has led to major changes in the phenology species such lilies (Liliales), mints (Lamiaceae), roses (Rosaceae), saxifrages (Saxifragales), and violets (Malpighiales) [31,32].

Changes in plant phenology could potentially have serious consequences on genetic diversity and ecological consequences for animals that depend on seasonal plant resource availability. Some studies have reported severe changes in the seasonal timing of bud burst and flowering in plants in response to changing climate over the past five decades [33,34]. Over the past 20–50 years, many plants have reacted to increasing temperatures by early flowering [35]. Several studies have reported such effects caused by changes in flowering phenology [36,37]. Furthermore, such studies reported genetic diversity of individual plant species in natural populations, particularly flowers and fruit-dependent animals [38,39]. Plant flowering time is determined by the integration of multiple environmentally sensitive gene pathways; climate change may alter these flowering time gene networks with important consequences for plant life history [40].

2.2 Plant-pollinator Interactions

Climate change will affect plant-pollinator mutualism for organism groups involved in pollination interactions. Such interaction is very important genetic diversity of plants and influence population persistence. Effective gene flows which maintain genetic diversity is contributed by flower density, timely synchronization of flowering periods and plant-pollinator interactions [41,42]. Changes in onset of flowers as a result of climate change have consequences on pollinators involved the first-appearance dates on flowers [43,44]. Previous study by Miller-Rushing et al. [45] has indicated that insect-pollinated plants generally react more strongly to increased warming than wind-pollinated plants.

In a latest study by Deutsch et al. [46] investigating how climate change will affect pollinators using empirical fitness curves related to the thermal tolerance of insects across the globe, they reported that tropical insects were most likely to experience deadly effects of warming due to their narrower thermal tolerance, despite the relatively lower temperature increase expected in tropical habitats. Such effects will significantly affect insect plant –pollinators' interactions hence affecting the genetic diversity of plants.

2.3 Seed Dispersal

Seed dispersal plays a very special role in the life cycle of most wild higher plants since it gives the ability of species to colonize new areas and connections to generations. It is the only opportunity for a plant to move to a site favorable for its establishment. The patterns of seed dispersal are determined in large part by the dispersal mechanism which has important implications for the demographic and genetic structure of plant populations [47]. In scenarios of present global change, dispersal is a particularly important life-history stage because it determines whether organisms can adjust their distribution to current and future changes in their abiotic and biotic environment [44].

Under climate change, seed and pollen dispersal has been reported have profoundly effects on the dynamics and genetic variation of plant populations [47]. A great concern exists that dispersal of many plant species will not be mobile enough to track suitable environmental conditions in pace with a rapidly changing climate, being finally condemned to extinction. Other species may face a reduction or increasing fragmentation of those areas that can sustain viable populations which will affect its genetic diversity.

Seed dispersal mechanism in plants can be mainly through wind, water and animals. Among those three dispersal mechanisms, the consequences of genetic diversity for wind dispersed plants as a result of climate change has previously been reported as not significant when compared to other dispersal mechanisms [48,49]. The study investigated a wind dispersed dwarf shrub *Salix herbacea*, where a loss of 50 per cent of its range was estimated to cause a loss of only 5 per cent of its genetic diversity because of its high dispersal ability. As a result of stronger winds caused by global warming, seeds and pollen are being carried over longer distances. Long distance dispersed seeds will have advantages over short distance dispersed seeds since long-distance-dispersed species create a genetic pattern which make species less vulnerable to loss of genetic diversity during range reduction as it has previously been reported [50].

2.4 Soil Seed Bank

Soil seed bank affect the genetic structure of populations and play a critical role in the vegetation dynamics of many plant communities [51]. Seed bank act as effective genetic reservoir preserving both the genetic composition and frequencies of alleles present in the population. Despite the important role played by seed banks in varying environments, the potential effects of climate change on this key process have rarely been considered. The strong mechanistic relationship between climatic factors and seed dormancy and germination suggests that climatic changes will affect seed bank persistence significantly [52,53]. As global temperature increased, increase in soil temperatures in open and sparsely vegetated habitats is expected, which could further accelerate the decline of seed viability and lower levels of relative success of recruitment, thus producing net losses to seed bank longevity [54].

Predicted changes in temperature, precipitation and soil moisture will affect many constituents of seed persistence in soil such as seed longevity, dormancy release and germination, and soil pathogen activity [54]. High temperatures are also likely to produce increased fire frequency. While fire may help to break the dormancy some seeds thus promoting seed germination, it can break seeds banks thereby increasing the risk of population decimation in species with high dependence on long lived seed banks [53]. Net losses to the seed bank can occur during this period due to either decreased seed viability or germination and seedling emergence into unsuitable conditions. Arnan et al. [55] has previously reported that seed-harvesting ants are more abundant under low vegetation cover and they disappear when the vegetation cover increases. Therefore as a result of climate change the activity of ants may increase in the open areas of the drought plots, resulting in an increase in seed removal also affecting seed bank.

2.5 Distribution of an Invasive Plant Species

An invasive species is a taxa that have been introduced beyond its accepted normal distribution and exert substantial negative impact on native biota, economic values, or human health [56]. Successful invasive species displace thriving native species by out competing them for space, food, water or habitat. Anthropogenic activities are known to be mostly responsible for the introduction of invasive species [57,58]. However, the climate change will play a direct role in promoting invasive species success and can become even more prevalent and destructive to genetic diversity of crop wild relatives and biodiversity as whole. For example Kriticos et al. [59] has reported that as a result of climate change *Acacia nilotica,* woody legume plant has become highly invasive in several parts of the world, including Australia where it has been declared a weed of national significance.

The spread of invasive species because of climate change is a threat to genetic diversity of crop wild relatives. This threat is largely due to fact that successful invaders exhibit surprisingly high levels of genetic variation, compete with the native species and rapidly adapt to local selective pressures for establishment replacing the native species. A typical example has been shown when assessing the invasive potential of *Tamarix ramosissima*, by examining the degree of genetic differentiation within and among populations from the latitudinal extremes of its introduced range [60]. Genetic differences in seedling root investment might have contributed to the ability of this species to successfully tolerate and invade a broader latitudinal range. It has been elsewhere reported that invasive species as a consequence of climate change can cause alteration in the diversity, nutrient cycles, forest succession, and fire frequency and intensity of some ecosystems [61].

Climate change will interact with other existing stressors to affect the distribution, spread, abundance, and impact of invasive species [62,63]. Climate change may cause some taxa that were in the past invasive to diminish in impact while previously noninvasive species to become invasive and many native species will shift their geographic distributions, moving into areas where they were previously absent [64,65,66]. As a result of consequences, the genetic diversity of plants will be adversely affected.

2.6 Increased Plant Pests and Pathogens

Climate change will have effect on plant pests by influencing a range of many insect pests and vectors which will expand or change, and new combinations of pests and diseases may emerge as natural ecosystems respond to altered temperature and precipitation profiles [66,67]. Climate change is mostly marked with increased temperature which is probably the single most important environmental factor influencing biotic interactions such as insect behavior, distribution, development, survival, and reproduction. Studies have shown that increased temperatures can potentially affect insect survival, development, geographic range, and population size [68,69]. Direct effect of plant pests can be through infesting the crop wild relatives reproductive structures (flowers buds, flowers, fruits and seeds) or by insects attacking other parts of the plant which in turn may reduce nutrient allocation for seed production [70]. This can have profound effects on plant genetic diversity as well as species distributions.

Increase temperature has also potential impacts on plant disease through both the host plant and the pathogen. Pathogens can be an important selective agent in plant evolution because they can severely reduce plant fitness and growth. Research has shown that some host plants become more susceptible to fungi and rust diseases with increased temperature [71]. Pathogen infection can severely reduce survivorship and reproduction of native plants. Previous studies suggest that pathogens affect a wide range of host plant traits including morphology, life history and mating system which are very important for maintaining genetic diversity and even community-level diversity [72,73].

3. CONSEQUENCES FOR THE LOSS OF GENETIC DIVERSITY

As explained earlier, climate change will in particular affect sexual systems, flowering phenology, and plant-pollinator and seed dispersal interactions in crop wild relatives and other plant species. Climate change impacts will also have detrimental effects on soil seed bank and in promoting invasive species success. The effect of climate change on influential factors for genetic diversity of plants may reduce genetic diversity and reproductive output hence loss of alleles for adaptation to future conditions. Studies by Alsos et al. [74] have previously reported that loss of genetic diversity in plants will vary considerably among species, and this variation could be elucidated by dispersal adaptation and by genetic differentiation among populations. Based on dispersal adaptation the study has further reported that herbs lacking adaptations for long-distance dispersal were predicted to lose genetic diversity at higher rate than dwarf shrubs adapted to long-distance dispersal. Plant populations with reduced genetic diversity are more susceptible to pest and disease outbreaks because of lower occurrence of resistant individuals within the population [75]. Under the ongoing climate change, serious consequences have already been reported for plant species including crop wild relatives linked to risk of local extinction [10,76]. The crop wild relatives represent a vital source of unexploited genetic diversity for crop improvement, thus the loss of their genetic diversity will result into a serious concern for food security.

4. CONSERVATION AND MITIGATION MEASURES NEEDED

An urgent conservation and mitigation measures are required in dealing with the future challenges of genetic diversity of plants especially in the context of changing climates. Constance et al. [77] urges that the best strategy is to mix different conservation approaches that help ecosystems to accommodate changes adaptively and mitigation strategies that enable ecosystems to reduce anthropogenic influences on global climate. Responding to this threat Root and Schneider [78] has recommended multi-taxon research effort to identify and prioritize species that are at risk due to climate change in order to inform governments of the seriousness of the threat and facilitate conservation adaptation and management. Investigations on population genetic diversity and structure of populations within a species particularly for the threatened species are also very important as some studies have reported [79,80,81]. Studies on genetic diversity of crop wild relatives may not only illustrate evolutionary histories, processes, and mechanisms but also will provide useful information for the biological conservation of the species.

Furthermore, for the conservation of plant genetic resources the following measures are recommended: It is important to assess and commence management actions through establishment of protected area network with appropriate management practices and restoration of degraded. Other conservation measures is through collection and establishment of threatened crop wild relatives in *ex situ* sites such as seed and field gene banks, botanical gardens, *in vitro* regeneration and deposition in DNA banks.

5. CONCLUSION

In this paper, it has been revealed that genetic diversity of plant species will be compromised due to the impact of climate change on factors which maintain genetic diversity, thus resulting into loss of genetic diversity. The loss of genetic diversity of plant may reduce the ability of plant species to cope with selective pressures which may lead to the extinction of the species. It is important to assess and commence conservation measures before the genetic diversity is lost. While *in situ* and *ex situ* are recommended, there is an urgent need for identification and conservation of threatened plants species that are at risk from climate change. Crop wild relatives are accredited as an important future source of genes and alleles for crop improvement; however they are threatened by climate change. Only effective conservation measures can assure their future survival and rich genetic diversity.

COMPETING INTERESTS

Author has declared that no competing interests exist.

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