# Chapter 20
# Genetic Vulnerability and Crop Loss: The Case for Research on Underutilized and Alternative Crops

**Laban K. Rutto, Vitalis W. Temu, and Myong-Sook Ansari**

**Abstract** The confluence of global climate change and population growth has brought to greater focus the question of how to satisfy future demand for food and fiber necessary to sustain current standards of living. Inevitably, agriculture will be called upon to do more at a time when established crops and cropping systems must confront new environmental and socio-economic challenges. Current efforts to preserve and characterize crop wild relatives and other genetic resources that could help crops meet future biotic and abiotic challenges are a direct response to the question. This chapter not only reiterates the importance of in situ and ex situ genetic conservation, it draws attention to the urgent need for investment in research on underutilized and alternative crops. The urgency relates directly to the fact that most of these crops are found in global biodiversity hotspots that are currently undergoing rapid environmental and socio-economic change.

**Keywords** Plant breeding and selection • Genetic vulnerability • Underutilized species • Crop wild relatives

## 20.1 Introduction

The concentration of modern agriculture on a few high yielding and universally accepted crops has resulted in two distinct phenomena:

(i) Hybrid crop varieties with narrow genetic bases relative to their wild relatives.
(ii) Declining food diversity among different cultures and communities as indigenous foods and practices are abandoned in favor of alternatives from (i) above.

Potential for worsening genetic vulnerability associated with a narrowing of the genetic base of economically important crops has been acknowledged and

L.K. Rutto (✉) • V.W. Temu • M.-S. Ansari
Agricultural Research Station, College of Agriculture, Virginia State University, Petersburg, VA 23806-0001, USA
e-mail: lrutto@vsu.edu; vtemu@vsu.edu; sookansari@yahoo.ca



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gene banks in developed and middle income countries are working to broaden the diversity of genetic material in their repositories. However, it is only recently that the erosion of cultures and loss of indigenous knowledge have been recognized as threats to genetic diversity and remedial measures proposed.

Globally, the conveniences of vertically integrated food systems are driving consumers to neglect local foods, some of which were traditionally sourced from the wild [1]. This chapter will address the question of genetic loss, and erosion of indigenous food cultures as a preamble to making a case for investment in research on underutilized and alternative crops.

## 20.2 Genetic Loss Through Selection and Breeding

The transition by the human race from hunter-gatherer to a sedentary lifestyle marked the advent of managed crop production. These early beginnings of modern agriculture were characterized by selection and domestication of wild plants with desirable traits, e.g., precocity, high yield, compact growth, and other positive attributes. Through repeated selection from this initial population of domesticated species, early agriculturalists isolated the genetic pools that now represent crops of economic importance. Table 20.1 summarizes the chronology of events marking this process and the fate of plant genetic diversity thereafter [2].

Although the initial isolation of a few species through selection and domestication may have resulted in the preservation of certain traits at the expense of others, the most significant genetic loss can be traced to the pressures imposed on plant genetic diversity by modern plant breeding. As demonstrated by Tanksley and McCouch [3] in Fig. 20.1, domestication and breeding have served as bottlenecks to genetic transfer that in the long term have resulted in a drastic narrowing of the genetic base of most crops.

Modern plant breeding has contributed to genetic loss by selecting parental lines from a small number of highly productive varieties to which a majority of improved

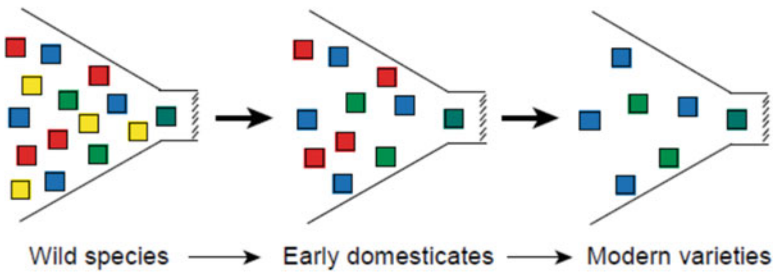


**Fig. 20.1** Genetic bottlenecks imposed on crop plants during domestication and through modern plant-breeding practices. *Boxes* represent allelic variations of genes originally found in the wild, but gradually lost through domestication and breeding. Such lost alleles can be recovered only by going back to the wild ancestors of our crop species (*Source*: Tanksley and McCough, 1997)

**Table 20.1** A history of the development and exchange of plant genetic resources

| Era | Year | Milestone |
|---|---|---|
| **Prehistoric era**<br>Domestication and geographical spread of crops | c. 8000 BC | • Humans start their transition from nomad hunters to sedentary farmers |
| | c. 4000 BC | • Cultural contacts and interactions result in crop diffusion and global transfer of plant genetic resources for food and agriculture (PGRFA) |
| **The past 5 millennia**<br>Development of agriculture and agricultural biodiversity | c. 3000 BC | • Sumerians and Egyptians actively collect PGRFA |
| | 1400 | • The discovery of America boosts intercontinental exchange of PGRFA |
| **The nineteenth and early twentieth centuries**<br>Science realizes the value and potential of genetic diversity | 1845 | • The Great Famine in Ireland dramatically demonstrates the need for genetic diversity in agriculture |
| | 1850 | • Charles Darwin and Gregor Mendel prove the importance of genetic diversity for biological evolution and adaptation |
| | 1920 | • Nikolai Vavilov identifies the main areas of crop origin and their genetic diversity |
| | 1960 | • The Green Revolution boosts productivity, but contributes to the loss of genetic diversity |
| **The 1960s to mid-1970s**<br>Scientific and institutional developments take place, but concerns remain about genetic erosion and vulnerability | 1965 | • The Food and Agricultural Organization (FAO) of the United Nations (UN) starts technical work on PGRFA collection and conservation, including a series of international technical conferences |
| | 1972 | • The UN Stockholm Conference on the Human Environment calls for strengthening of PGRFA conservation activities The US National Academy of Sciences raises concern over the genetic vulnerability of crops after a major maize epidemic |
| | 1974 | • What is now the International Plant Genetic Resources Institute was established to support and catalyze collection and conservation efforts |
| **Late 1970s to early 1990s**<br>The first major policy developments | 1978 | • The International Union for the Protection of New Varieties of Plants was established in 1978 and revised in 1991. National legislation in many countries restricts access to PGRFA, including through intellectual property rights |

(continued)

**Table 20.1** (continued)

| Era | Year | Milestone |
|---|---|---|
| | 1979 | • FAO member countries start policy and legal discussions, leading to the first permanent intergovernmental forum on PGRFA in 1983—the Commission on Genetic Resources for Food and Agriculture (CGRFA)—and the adoption of the non-binding International Undertaking (IU) on Plant Genetic Resources |
| | 1989 | • Non-governmental organizations promote an international dialogue on PGRFA, reaching common understandings that feed into the CGRFA's negotiations |
| **1992 to the present day**<br>An era of global instruments and legally binding agreements | 1992 | • The first international binding agreement on biological diversity in general, the Convention on Biological Diversity, is adopted. Its members recognize the special nature of agricultural biodiversity and support the negotiations of the FAO |
| | 1993 | • The CGRFA agrees to renegotiate the IU, resulting in the adoption in 2001 of the legally binding International Treaty for Plant Genetic Resources for Food and Agriculture (ITPGRFA)<br>• The CGRFA develops the Leipzig Global Plan of Action on plant genetic resources and the first report on the state of the world's PGRFA |
| | 1994 | • The Marrakech Agreement on Trade-Related Aspects of Intellectual Property Rights is adopted |
| | 1995 | • The CGRFA broadens its mandate from only crops to all components of biodiversity for food and agriculture, including farm animals, forestry, and fisheries |
| | 2004 | • The ITPGRFA enters into force on 29 June |
| **Agreed future steps** | 2006 | • The first meeting of the governing body of the ITPGRFA will take place in June 2006 in Spain<br>• The CGRFA is to adopt its Multi-Year Program of Work, covering all agricultural biodiversity sectors |

Adapted by permission from Macmillan Publishers Ltd: Nature Reviews Genetics (Esquinas-Alcázar, J.: Protecting crop genetic diversity for food security: political, ethical and technical challenges, copyright 2005) lines among cultivated crops can be traced. This narrowing of the genetic base has rendered most crops vulnerable to biotic and abiotic pressures and jeopardized the potential for future genetic improvement of economically important crops. A number of studies on the extent of genetic loss in crops of economic importance have been carried out with varying results. For example, Fu and Somers [4] link widespread allelic gene reduction in Canadian hard spring wheat starting from the 1930s to pressures exerted by modern plant breeding, while Duvick [5] noting an improvement in the genetic base of field crops in the USA in 1981 relative to 1970 concluded at the time that genetic vulnerability was not a major threat to US field crops.

In the case of soybean, it has been found that although the genetic bottlenecks imposed by breeding and selection have negatively impacted the genetic base, the most significant reduction in genetic diversity occurred at domestication when the low sequence diversity present in wild species was halved and 81 % of rare alleles lost [6]. Jordan et al. [7] report that selection for resistance to sorghum midge (*Stenodiplosis sorghicola*) in Australia had been achieved at the expense of diversity, a situation that may lead to genetic vulnerability, and in future, impact the rate of progress in breeding for yield. It is for the same reasons that Hammons [8] has proposed breeding strategies for widening the genetic base and increasing genotypic diversity of economically dominant peanut (*Arachis hypogea*) cultivars in the USA.

As a general theme, the various studies emphasize the dangers of genetic loss and identify mechanized monoculture as a major contributor to genetic erosion. In a review of the Indian green revolution, Safeeulla [9] associates the shift from traditional crops and age-old practices to high yielding varieties with increased vulnerability and potential for future crop epidemics. Jacques and Jacques [10] echo the same concerns about the dangers of mechanized monoculture both from the perspective of genetic loss and in terms of its contribution to the erosion of social and cultural diversity.

## 20.3 Genetic Loss Through Crop Loss

Most of what are considered lost crops comprise of species native to tropical and sub-tropical regions of Africa and Latin America that were the pre-colonial staple foods of indigenous communities. One of the pervasive consequences of colonialism was the introduction of food crops from the northern hemisphere and sequestration of land for large-scale production of industrial crops like rubber, sugarcane, and cotton. These activities diminished the stature of native crops and began a process of neglect and genetic loss from which native food crops are yet to recover. An excerpt from the introduction to the "Lost Crops of the Incas" notes how at the time of Spanish conquest, the locals cultivated a large number of diverse crops:

> On mountainsides up to 4 km high, along the spine of a whole continent, and in climates varying tropical to polar, they grew a wealth of roots, grains, legumes, vegetables, fruits and nuts [11].

The book identifies a significant number of Inca root and tuber crops, fruits, and some grains, legumes, vegetables, and nuts that would benefit from research and development to facilitate introduction and commercial production in regions beyond their centers of origin. The US National Research Council has also published three volumes on the Lost Crops of Africa covering grains, vegetables, and fruits. Among grains, the authors single out fonio (*Digitaria exilis*) and tef (*Eragrostis tef*) as consumed solely by Africans. Other species addressed include African rice (*Oryza glaberrima*), a number of millets and sorghums, and other wild and cultivated grains [12]. The edition on vegetables discusses 18 species of which some, e.g., Okra (*Abelmoschus esculentus*) and Cowpea (*Vigna unguiculata*) are cultivated worldwide but originated from Africa where there remains a large selection of uncharacterized germplasm [13]. The companion volume on fruits lists 10 cultivated and 14 wild species that according to the authors have virtually not been touched by science [14].

Although the most important indigenous crops have been identified and their cultural and economic value acknowledged, the threat of extinction still exists. In the current era, the loss of native species including indigenous crops can be linked to environmental pressures exerted by population growth as documented by Cincotta et al. [15] and others like Maurer [16] who has demonstrated a direct relationship between the increasing fraction of solar energy consumed by humans and loss in biodiversity. Furthermore, human activities common to many developing countries, e.g., uncontrolled logging, unregulated mining, slash and burn agriculture, overgrazing, and commercial hunting can lead to ecosystem degradation and species loss even in the absence of widespread human settlement.

Climate change is another factor that is contributing to habitat loss and a shift in species composition. For example, climate models predict a 51–65 % loss of the Fynbos biome in South Africa by 2050, an event that would result in complete dislocation of up to 10 % of Proteaceae endemic to the region [17]. This observation underlines the need for urgent intervention measures particularly in developing countries with limited infrastructure for tracking and reporting changes in climate and biodiversity.

## 20.4 Global Response to Genetic Vulnerability and Crop Loss

In the nineteenth century Vavilov identified the main areas of origin and genetic diversity of cultivated plants and highlighted the potential of wild relatives as sources of genetic material for improving modern crops [18]. His work and other events including the Southern corn leaf blight epidemic of 1970–1971 [19] motivated the collection of races and species related to cultivated plants and the establishment of gene banks.

Currently, collection, cataloging, and preservation of germplasm are widespread and well-coordinated with most nations maintaining repositories for economically important crop accessions and landraces. In the USA, the system established by congress after the 2nd World War to maintain and distribute plant genetic resources has grown into a National Plant Germplasm System consisting of 26 repositories with more than half a million individual collections [20]. Another notable initiative in the effort to preserve plant genetic diversity is the Svalbard Global Seed Vault in Norway. Established by Cary Fowler jointly with the Consultative Group on International Agricultural Research (CGIAR), the vault is serving as a repository for duplicate copies of seeds held in gene banks worldwide with more than 840,000 samples from 4000 distinct species secured by the year 2015.

The science of conservation spearheaded largely by international agencies like the Food and Agriculture Organization (FAO) of the United Nations, Bioversity International, and the International Plant Genetic Resources Institute (IPGRI) has progressed apace. Together with other agencies and institutions of higher learning, they have generated considerable knowledge and information on the science and practice of conservation, characterization, and sharing of genetic material. Good examples include a manual for in situ conservation of crop wild relatives released by Bioversity International in 2011 [21], and the recently published revision to gene bank standards for plant genetic resources [22].

Hammer [23] examines what he finds to be defining shifts in the field of plant genetic resources driven largely by scientific advancements starting from the 1990s. These changes include:

(i) Increasing emphasis on in situ as opposed to ex situ conservation, against which he recommends a judicious and balanced approach.
(ii) A shift in priority from major cultivated species to underutilized and neglected crops as a means of maintaining species diversity. This change is motivated by the realization that of the more than 7000 cultivated plants, only 100 account for a majority of holdings in gene banks worldwide.
(iii) Utilization of emerging tools including genetic analysis to expand on existing collection strategies by examining landrace populations and their potential productive components in order to optimally conserve genetic diversity.
(iv) Exploration of approaches for decreasing gene erosion by increasing participation in maintenance and use beyond the gene bank. Others including Tanksley and McCouch [3] and Wright [24] have previously called for policy and technical changes to optimize the utilization of genetic material already at the disposal of gene banks.
(v) Greater emphasis on molecular tools for the evaluation of gene bank material. Here too Hammer [23] warns against wholesale neglect of traditional methods and recommends measured application of both new and old technologies.
(vi) Recognition of the need for a strategy on large-scale reproduction and replacement of ex situ accessions before loss of viability.

In conclusion, Hammer [23] puts forward the idea of an integrated gene bank that combines the new aspects of molecular biology and biodiversity with classical conservation, evaluation, and utilization tasks while staying abreast of in situ and other dynamic conservation strategies.

However, as observed by Ledig [25], the technical aspects of gene preservation ex situ in seed banks and arboreta or in situ in reserves or special management areas are fairly simple. It is ecosystem level processes, e.g., the roles that co-evolution and adapted gene complexes play in the preservation of genetic diversity that still pose difficult research questions. Furthermore, as noted in his examination of strategies for conserving forest genetic resources, socio-economic factors associated with land as an economic resource may be the greatest challenge to genetic conservation in situ, an observation supported by Zimmer [26] who found that the value of native crops in the southern Peruvian highlands was impacted by shifts in access to land, labor, and capital, the socio-cultural value of the crop, and the biogeographic patterning of cultivars. For this reason, he recommends that in situ conservation programs be pursued only after fully understanding conditions upon which continued production of target crops is contingent.

Genetic erosion through neglect or loss of indigenous crops and knowledge has not received as much attention as genetic loss due to selection and breeding. Interest in indigenous plants with economic or cultural value started in the 1950s and continues to increase but the many works on ethnobotany and ethnomedicine (Fig. 20.2) largely document novel and historical usage. It is only in the 1980s that serious effort to characterize, conserve, and improve indigenous crops and other neglected species started with the formation of the International Center for

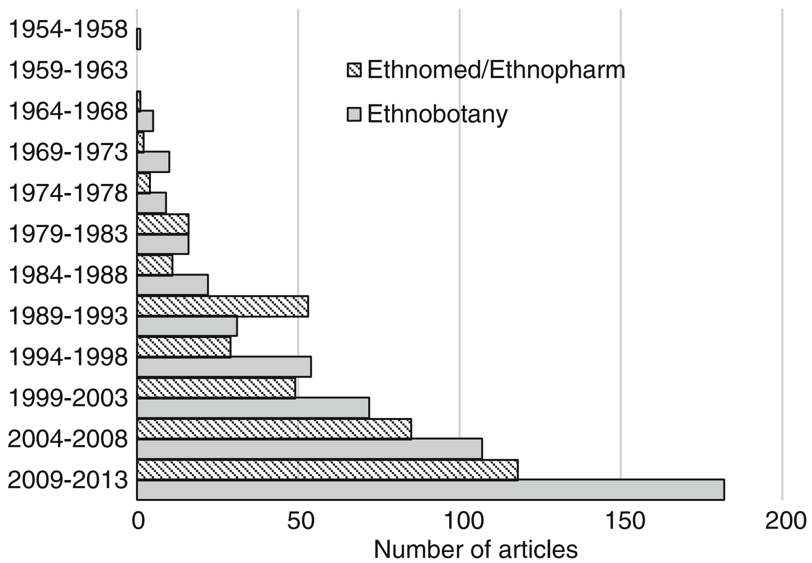


**Fig. 20.2** Number of articles with ethnobotany, or either ethnomedicine or ethnopharmacology, in the title that were published in peer-reviewed periodicals between 1954 and 2013 (*Source*: Scopus, http://www.scopus.com/home.url)

Underutilized Crops (ICUC), an independent research institute that supported and coordinated research programs to increase productivity and use of neglected and underutilized crops. Renamed Crops for the Future (CFF) after merging with the Global Facilitation Unit for Underutilized Species (GFU) in 2009, the organization continues to coordinate and conduct research on underutilized crops. Other organizations including FAO, Bioversity International, IPGRI, and international development agencies like the Department for International Development-DFID (United Kingdom) and the German Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ) are also involved in research and development on indigenous crops and other underutilized species.

Review of literature suggests that the effort is starting to bear fruit. A sampling from an emerging stream of peer-reviewed work on indigenous crops and other underutilized species research shows activity in diverse areas including conservation and use [27–29], climate change [15, 17, 30], agronomy [31], genotyping [32], breeding [33], human nutrition [34–37], and market research [38–41]. Meetings dedicated solely to underutilized species have also been convened, e.g., by the American Society for Horticultural Science [42], the International Atomic Energy Agency [43], the International Society for Horticultural Science [44–46], and Bioversity International [47]. However, there remains a lot of ground to be covered before a fully functional research and development framework for underutilized plant species can be realized [48, 49].

## 20.5 Research on Underutilized and Alternative Crops

As mentioned in the introduction, limited research and development on neglected and underutilized species is a contributor to gene erosion and food insecurity. Most of such species are to be found among indigenous communities where they are grown or harvested for food, medicine, or cultural purposes. For example, van Andel [50] found that descendants of enslaved Africans in Suriname still grow African rice (*Oryza glaberrima*) for food and ritual. The same applies to most cultivated/harvested species native to Africa that are discussed in the volumes on lost grains, vegetables, and fruits published by the US National Research Council [11–14].

A defining quality of these species that arises directly from limited genetic manipulation is strong adaptability and resilience. A majority of the plants are produced in low-intensity, low input systems, and some survive in the wild. Most of them are also highly efficient in resource utilization and show a high tolerance for regional biotic and abiotic stresses. The trend to direct attention away from major cultivated crops to underutilized species reported by Hammer [23] as among paradigm shifts informing the field of plant genetic resource conservation is driven in part by the realization that some underutilized species possess genes and traits that may be useful for future crop improvement and global food security.

The fact that a large number of indigenous crops and other plants of economic importance native to the tropical and sub-tropical belt have not received commensurate scientific attention is a major obstacle to their preservation and commercialization. They are not yet optimized for large-scale production and postharvest processing, and are vulnerable to displacement by introduced species including newly developed genetically modified strains. Limited scientific testing also means that the responses of most native germplasm to ecological shifts associated with global climate change remain unknown. In their totality, these circumstances preface potential widespread decline in genetic diversity and crop loss that in Africa and other regions presently witnessing rapid urbanization and other social change will have serious implications for food security and socio-economic sustainability.

Furthermore, it must not be assumed that neglect of species with economic potential is limited to the regions addressed in the four cited volumes published by the US National Research Council. The highly evolved food production and distribution systems common to the USA and other developed countries ensure that consumers have year-round access to a limited variety of fresh produce and no longer have to eat according to season, or live off the land. For this reason, a number of edible plants originally grown as niche crops or foraged from the wild are no longer consumed and have fallen into neglect. For example, in a survey of Virginia flora, we found more than 500 wild and cultivated species with an edibility or medicinal rating higher than 3 (max 5) as ranked by the Plants for a Future database (Fig. 20.3). We also found that about half of species rated 5 either for edibility or medicinal value were introduced (Table 20.2), confirming their importance to earlier settlers [51]. Similarly, Stamp et al. [52] observe that a majority of underutilized

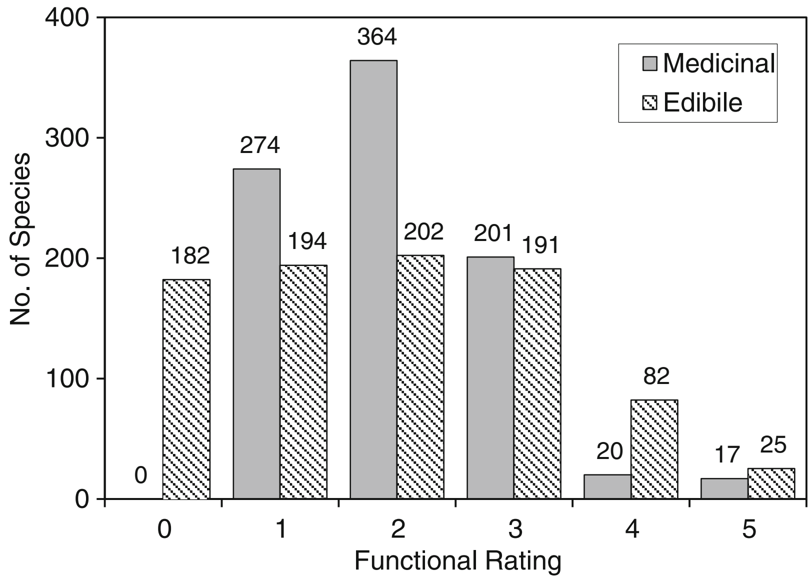


**Fig. 20.3** Number of wild and cultivated edible and medicinal plants found in Virginia (Digital Atlas of the Virginia Flora: http://vaplantatlas.org/). Functional ratings (0–5) courtesy of Plants for a Future (http://pfaf.org/)

**Table 20.2** Wild and cultivated edible and medicinal plants found in Virginia

| Common name | Botanical name | Edible[a] | Medicinal[a] | Origin[b] |
|---|---|---|---|---|
| Marsh Mallow | *Althaea officinalis* | 5 | 5 | Not specified |
| Stinging Nettle | *Urtica dioica* | 5 | 5 | Introduced |
| Wild Leek | *Allium ampeloprasum* | 5 | 3 | Introduced |
| Winter Squash | *Cucurbita maxima* | 5 | 3 | Introduced |
| Squash | *Cucurbita moschata* | 5 | 3 | Introduced |
| Fennel | *Foeniculum vulgare* | 5 | 3 | Introduced |
| Peach | *Prunus persica* | 5 | 3 | Introduced |
| Raspberry | *Rubus idaeus* | 5 | 3 | Native |
| Sassafras | *Sassafras albidum* | 5 | 3 | Native |
| Small Reed Mace | *Typha angustifolia* | 5 | 3 | Native |
| Reedmace | *Typha latifolia* | 5 | 3 | Native |
| Sweet Violet | *Viola odorata* | 5 | 3 | Introduced |
| Nodding Onion | *Allium cernuum* | 5 | 2 | Native |
| Chives | *Allium schoenoprasum* | 5 | 2 | Introduced |
| Hawthorn Hybrid | *Crataegus missouriensis* | 5 | 2 | Native |
| Goumi | *Elaeagnus multiflora* | 5 | 2 | Introduced |
| Elaeagnus | *Elaeagnus pungens* | 5 | 2 | Introduced |
| Sunflower | *Helianthus annuus* | 5 | 2 | Introduced |
| Common Day Lily | *Hemerocallis fulva* | 5 | 2 | Introduced |
| Musk Mallow | *Malva moschata* | 5 | 2 | Introduced |
| Common Reed | *Phragmites australis* | 5 | 2 | Not specified |
| Plum | *Prunus domestica* | 5 | 2 | Introduced |
| Ramanas Rose | *Rosa rugosa* | 5 | 2 | Introduced |
| American Persimmon | *Diospyros virginiana* | 5 | 1 | Native |
| Duck Potato | *Sagittaria latifolia* | 5 | 1 | Native |
| Hop | *Humulus lupulus* | 4 | 5 | Introduced |
| Balsam Fir | *Abies balsamea* | 3 | 5 | Introduced |
| Lesser Burdock | *Arctium minus* | 3 | 5 | Introduced |
| Shatavari | *Asparagus racemosus* | 3 | 5 | Introduced |
| Lemon Balm | *Melissa officinalis* | 3 | 5 | Introduced |
| Evening Primrose | *Oenothera biennis* | 3 | 5 | Native |
| Sage | *Salvia officinalis* | 3 | 5 | Introduced |
| Milk Thistle | *Silybum marianum* | 3 | 5 | Introduced |
| Comfrey | *Symphytum officinale* | 3 | 5 | Introduced |
| Slippery Elm | *Ulmus rubra* | 2 | 5 | Native |
| Agnus-Castus | *Vitex agnus-castus* | 2 | 5 | Introduced |
| Echinacea | *Echinacea purpurea* | 1 | 5 | Introduced |
| Witch Hazel | *Hamamelis virginiana* | 1 | 5 | Native |
| German Camomile | *Matricaria recutita* | 1 | 5 | Introduced |

[a]Edibility and medicinal ratings courtesy of Plants for a Future (http://pfaf.org/)
[b]Information on origin obtained from the Digital Atlas of the Virginia Flora (http://vaplantatlas.org/)

crops that were once widely grown in Europe are no longer suitable for today's agriculture and call for long-term breeding programs and other initiatives to stem the erosion of biodiversity.

## 20.6 Conclusion

Conservation, improvement, and commercialization of indigenous and underutilized crops demand urgent and coordinated effort on a scale similar to that invested in ex situ preservation of genetic diversity. This is necessitated by global climate change, human encroachment, and other socio-economic factors that cumulatively threaten biodiversity. According to Williams and Haq [47], there is still a lot of work that remains to be done. In their assessment of the state of global research on underutilized crops, they found that despite resurgent interest in underutilized crops as well as recognition of the interconnection between agriculture and the environment, policies supportive of underutilized crops remain underdeveloped.

Furthermore, this field of research is unlikely to attract private investment because underutilized crops are generally unsuited to modern agriculture [52]. As observed by Rubenstein et al. [53], private investment in conservation often falls far short of public objectives even for established crops because plant genetic resources are considered a public good. This puts the onus on governments to enact favorable policies, and to dedicate resources in support of work on underutilized and other alternative crops.

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