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RESEARCH ARTICLE

Investigating the exchange of plant material between European and African botanical institutions for research and development

Ayenew Ashenafi[1,4†] | Paul Smith[2] | Michael Kiehn[3] | Feleke Woldeyes[4] | Sebsebe Demissew[1]

[1]Department of Plant Biology and Biodiversity Management, Addis Ababa University, Addis Ababa, Ethiopia

[2]Botanic Gardens Conservation International, Surrey, UK

[3]Core Facility Botanical Garden, University of Vienna, Wien, Austria

[4]Ethiopian Biodiversity Institute, Addis Ababa, Ethiopia

Correspondence
Sebsebe Demissew, Department of Plant Biology and Biodiversity Management, Addis Ababa University, Addis Ababa, Ethiopia.
Email: sebseb.demissew@gmail.com

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Social Impact Statement

The exchange of plant material and data is essential for supporting collaborative research efforts to address global challenges. In order to promote collaboration between Plant Genetic Resource (PGR) organizations in conservation research and development and to improve the sustainable utilization of PGRs, constraints to plant material and data exchange must be addressed. This can only be achieved through the introduction of policy measures that will build trust among institutions and encourage facilitated plant material exchange, equitable benefit sharing, and compliance with Access and Benefit Sharing (ABS) instruments. The resulting improvements in the conservation and sustainable utilization of PGRs will improve food security, public health, livelihoods, sustainable development, and ecological sustainability.

Summary

- The aim of this study was to assess the extent of plant material exchange between European and African Plant Genetic Resource (PGR) organizations for research and development.
- Data were collected from Index Seminum databases and through a survey questionnaire. They were statistically analyzed using a chi-square test and Spearman correlation coefficient using SPSS, version 25.
- The study indicated that the extent of plant material exchange between African and European PGR organizations for research and development is insignificant compared with the exchange between European institutions. Plant material exchange usually included benefit sharing, and the most commonly shared benefits were knowledge transfer, participation in research, access to research results, and joint authorship of publications. Many of the respondents were not very familiar with Access and Benefit Sharing (ABS) principles and regulations. The major constraints to plant material exchange were found to be cumbersome bureaucratic procedures, poor knowledge of compliance requirements, lack of

† This article is dedicated to the memory of our colleague and friend Ashenafi Ayenew, who passed away after a short illness in May 2023.

national ABS regulations, poor quality of data associated with collections, and lack of tracking mechanisms.

- The low level of plant material exchange between African and European institutions is also most probably due to limited human and technological capacity in African institutions that restrict their involvement in research and development. Therefore, there is a need to build trust and to increase human and technological capacities for research in African institutions to strengthen collaboration by ensuring facilitated exchange and equitable benefit sharing.

KEYWORDS
African, European, plant material exchange, tracking mechanisms, access and benefit sharing

1 | INTRODUCTION

Plant Genetic Resources (PGRs) have always provided humans with their basic needs, such as food, medicines, and shelter, and remain today the basis of modern scientific innovation, adaptation, and resilience, underpinning modern natural resource management in the landscape. PGRs are essential for long-term food security, sustainable utilization of non-food products, plant conservation, and adaptation to a changing climate. All countries are now highly dependent upon PGRs located (or originally collected from) beyond their borders (Halewood et al., 2014), and increased future interdependence is predicted because of challenges such as climate change (Fujisaka et al. 2011 cited in Galluzzi et al., 2016).

The legal and facilitated exchange of plant material and data is essential to support collaborative research, biodiversity conservation, and sustainable development. The exchange of plant material by botanical institutions is governed by the principles of the Convention on Biological Diversity (CBD) and particularly the Access and Benefit Sharing (ABS) regulations of the Nagoya Protocol (CBD Art. 15 and Nagoya protocol Art. 5–9). Material exchange is generally only for non-commercial use and is covered by Material Transfer Agreements (MTAs) that stipulate how plant material can be used and how benefits from such use should be shared.

The International Plant Exchange Network (IPEN) has been developed to provide a common framework for the exchange of plant materials for non-commercial use between participating botanical institutions. The IPEN Code of Conduct sets out principles related to the acquisition, documentation, maintenance, and supply of living plant material within and beyond the IPEN system as well as on benefit-sharing (Kiehn & Löhne, 2018). It also provides a standardized template for MTAs to be used for plant material exchange with institutions that are members and non-members of IPEN (O'Donnell & Sharrock, 2018). A key aspect of the IPEN Code of Conduct is that plant material transferred within the network may only be used for non-commercial purposes of scientific research, education, conservation, raising public awareness, and display. The IPEN Code of Conduct has been adjusted to fully comply with the provisions of the Nagoya Protocol (Kiehn & Löhne, 2018).

The impacts of climate change on the conservation of species in the wild and the use of domesticated species for human needs make ex situ conservation and exchange of PGR more important than ever. The increasing effects of climate change on plant distributions in situ has made the application of ex situ PGR management techniques even more crucial. Knowledge and data gained in managing ex situ populations can be used to inform the management and adaptation of species and ecosystems to changed conditions in the wild (SCBD, 2009). Climate change will also engender a demand for novel plant germplasm of all kinds suited to new eco-climatic conditions, and plant introductions will assume a new importance. Plant introduction has remained largely unchanged over the past 400 years and is often ad hoc, poorly organized, and insufficiently collaborative, but if it is to meet the needs of today's situation, it needs to be overhauled (Heywood, 2011).

An important aspect of successful ex situ plant conservation, material exchange, and research is to connect institutions and researchers to living plant collections. Facilitating the use of living collections to support research and connecting individual collections to the rest of the world is crucial. In addition, collaboration between the broader botanic garden and plant conservation communities can increase the value and use of an individual collection and support broader conservation, research, and human development efforts as well as serving as an insurance policy against the loss of that germplasm at a single institution (Cibrian-Jaramillo et al., 2013).

The impact of individual botanic gardens, in terms of conservation, research, and education, has been significantly increased by the establishment of effective national and international networks (Borsch & Löhne, 2014). Although networking for conservation has resulted in numerous reported positive results (e.g., Rivière et al., 2018), the activities undertaken by botanic gardens and seed banks need to be better integrated to ensure that shared priorities can be developed and that experiences, resources, and technologies can be shared. There are still serious gaps in capacity for ex situ conservation and research, especially in Africa, parts of Asia, the Caribbean, Latin America, and the Middle East, where the existing institutions involved are often poorly resourced (SCBD, 2009). In this context, it is useful to assess existing European and African collaborative research in plant conservation and sustainable development.

This study aims to assess the extent and nature of plant material exchange between European and African botanical institutions and to identify constraints associated with the exchange of plant material. The results of this study will contribute to developing mechanisms and tools to overcome these constraints, strengthening collaboration, and broadening the extent and nature of plant material exchange. The focus of the study is on the exchange of plant material for non-commercial scientific research and development purposes that ensure the conservation of plant diversity and sustainable development. The scope of this pilot study focuses on botanic gardens and PGR institutions that exchange plant material subject to the Nagoya Protocol. It does not include agricultural genebanks that exchange plant material based on the International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA) or the multilateral system Standard Material Transfer Agreements (SMTAs).

2 | MATERIAL AND METHODS

Data were collected from a meta-database of Index Seminum plant material exchange records to identify plant material exchange levels and primary data. These data are based on responses to a request for information on plant material exchange sent out to European botanical institutions and are therefore not comprehensive. Nevertheless, nearly 7000 material exchange interactions initiated by 17 European botanical institutions over a 23-year period were assessed (Table 1). In addition, an online survey was administered from February 16 to March 16, 2021, to obtain information on the extent, nature, and modalities of plant material exchange and to identify the various perspectives, constraints, and opportunities associated with plant material exchange. Descriptive statistical methods, percentage and frequency, chi-square tests, and Spearman correlation coefficients were used to analyze the data using IBM SPSS statistics software, version 25 (IBM Corp. 2017).

3 | RESULTS

A total of 64 respondents from 34 countries participated in the online survey. Among these, eight countries were African and 18 were European. The remaining eight countries were from Asia, N. America, and S. America and categorized as "non-European" for the purpose of this study. Most of the respondents were from botanic gardens/arboreta (46; 71.9%), followed by university/higher learning institutions (8; 12.5%), gene banks (2; 3.1%), and research institutions (1; 1.6%). The remainder (7; 10.9%) were from zoological gardens, plant-breeding companies, conservation charities, cemeteries, private companies, and conservation NGOs.

TABLE 1 Plant material exchange records assessed during this study and destinations of plant material sent out in seed form.

Institution records assessed (country)	Time period	No. of exchange interactions			Total
		A	E	NE	
Graz Botanic Garden (Austria)	2019	0	85	15	100
University of Vienna Botanical Garden (Austria)	2019–2020	0	10	22	32
Frankfurt Palm Garden (Germany)	2006–2020	6	396	154	556
Frankfurt Botanical Garden (Germany)	2011–2020	2	173	66	241
Reykjavik Botanic Garden (Iceland)	2017–2020	0	87	39	126
Siena Botanical Garden (Italy)	2002–2020	15	2393	595	3003
Botanical Garden of the University of Latvia (Riga), National Botanic Garden of Latvia (Salaspils), and Latvia's State Forests Kalsnava Arboretum (Latvia)	2019	0	200	80	280
Klaipėda University Botanic Garden (Lithuania)	2020	0	48	12	60
Botanical Garden of the University Marie Curie, Lublin (Poland)	2020	0	125	17	142
Botanical Garden of the Adam Mickiewicz University (Poland)	2020	0	53	7	60
Botanical Garden of Medicinal Plants, Wroclaw Medical University Kochanowskiego (Poland)	2019–2020	1	181	44	226
Ogród Dendrologiczny w Przelewicach (Arboretum Przelewice) (Poland)	2020	0	22	3	25
University of Alcalá (Spain)	1997–2014	8	847	248	1103
Bergius Botanic Gardens (Sweden)	2006–2019	2	225	72	299
Linnaean Gardens of Uppsala (Sweden)	2017–2020	0	533	170	703
Total no. of exchange interactions	**1997–2020**	**34**	**5378**	**1544**	**6956**

Abbreviations: A, African; E, European; NE, Non-European.

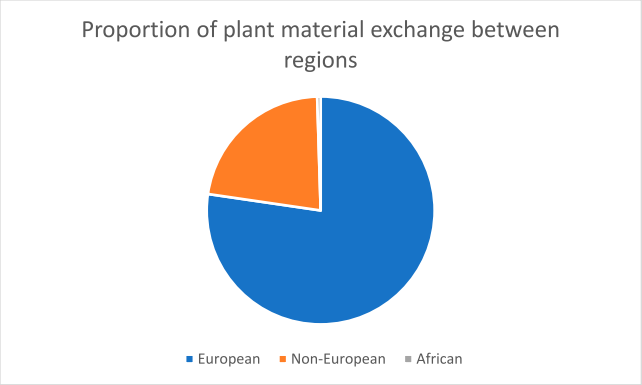

FIGURE 1 Proportion of plant material exchanged between 17 botanical institutions in different regions of the world between 1997 and 2020 ($n = 6956$ exchanges).

3.1 | Extent of plant material exchange

Analysis of data on the exchange of plant material from seventeen institutional records indicated that the exchange of plant material between European and African institutions occurs very rarely (Figure 1). It accounted for less than 1% (0.49%) of the total proportion of material exchanged at the institutions concerned during the study period. Only four African countries were involved in material exchange, and these were Algeria, Egypt, South Africa, and Tunisia. Plant material exchange occurred most frequently among European institutions, with 77.31% of the PGR material exchanged being between European institutions. Plant material exchange between European and Non-European institutions accounted for 22.2% of the material exchanged.

3.2 | Survey results

According to the survey data analysis, most respondents (45; 81.8%) indicated that their organization provided plant material to foreign organizations, and the remainder (10; 18.2%) did not. Among those who provided plant material to foreign organizations, only 14 (31.1%) indicated the countries to which they provided the material. Most of these provided materials to European countries (70.6%), followed by Non-European (29.4%), and none provided material to African countries. The most frequently mentioned recipient countries were Germany, Italy, and the USA. Similarly, most respondents (47; 85.5%) confirmed that their organization received plant material from foreign organizations, and the remainder (8; 14.5%) did not. Among those who received plant material from foreign organizations, only 15 (31.9%) indicated the countries from which the material was received. Again, most received material was from European countries (63.1%), followed by non-European (35.4%) and then African (1.5%). The most frequently mentioned provider countries were Germany, Italy, and the USA.

Regarding the frequency of plant material provided to foreign organizations, 14 respondents (31.1%) reported that they distributed plant material very frequently (>50 material transfers per year), 12 respondents (26.7%) distributed material frequently (10–50 material transfers per year), 15 respondents (33.3%) distributed material infrequently (<10 material transfers per year), and four respondents (8.9%) distributed material rarely (<1 material transfer per year).

Similarly, 11 respondents (23.4%) reported that they received plant material very frequently (>50 material transfers per year), 12 (25.5%) received material frequently (10–50 material transfers per year), and the remaining respondents (15; 31.9% and 9; 19.2%) reported that they received material infrequently (<10 material transfers per year) and rarely (<1 material transfer per year), respectively. The frequency of plant material provided and received was found to be highly significant and positively correlated (Spearman test, $r = 0.513$, $p = 0.01$, $n = 55$).

3.3 | Trends in plant material exchange

The survey results indicated that the trends in sending out plant material to foreign organizations over the past five years were probably steady. Here, 25 respondents (48.08%) indicated that they thought the exchange of material was about the same over recent years, 16 respondents (30.77%) thought it was decreasing, and 11 respondents (21.15%) thought that it was increasing. Similarly, the trend in receiving material was found to be steady by 24 respondents (47.06%), decreasing by 17 respondents (30.33%), and increasing by 10 respondents (19.61%).

3.4 | Type of plant material and data exchanged

More than half of the survey respondents (31; 59.6%) exchanged plant material and its associated data, whereas 17 (32.7%) exchanged data sometimes and four (7.7%) exchanged plant material without its associated data. The type of data mainly exchanged was passport data, such as taxon name, collection no., date, location, and time of collection (47; 97.9%). One respondent (2.1%) stated that plant material exchange also involved associated traditional knowledge.

The types of plant material exchanged were found to be diverse. Almost all respondents exchanged living seeds (45; 97.8%), and nearly half of the respondents also exchanged living plants (19; 41.3%). Some also exchanged herbarium specimens (13; 28.3%), DNA samples (8; 17.4%), and plant extracts such as oils, gums, and resins (3; 6.5%). Tissue culture, ethnobotanical specimens, and silica-dried tissue were also exchanged, although rarely (1; 2.2%).

3.5 | Plant collections of foreign origin

Forty-five respondents (86.5%) reported that they hold plant collections of foreign origin, whereas seven respondents (13.5%) do not

hold foreign-origin material in their plant collections. Some estimated that more than 75% of their collections are of foreign origin (10; 25%), and some other respondents estimated foreign-origin material to be in the range of 50%–74% (13; 32.5%). The remaining respondents estimated foreign material to be 25%–49% (8; 20%) and less than 25% (9; 22.5%) (Figure 2).

3.6 | Mechanisms of plant material exchange

About half of the respondents (23; 50%) use MTAs to obtain plant material from foreign PGR organizations. Plant material is also obtained through access permits (14; 30.4%), collaborative research agreements (13; 28.3%), and loan agreements (4; 8.7%). Material was also freely accessed with consent by some respondents (13; 28.3%), and seven respondents (15.2%) said they freely accessed plant material without consent.

Provision of material followed similar trends, with MTAs (18; 38.3%) and SMTAs (16; 34%) accounting for the majority of mechanisms of plant exchange. Free access with consent was provided by 10 (21.3%) respondents, and eight respondents (17%) provided material under collaborative research agreements. Access permits (6; 12.8%), loan agreements (4; 8.5%), IPEN agreements (4; 8.5%), and export permits (1; 2.1%) were also used. Only two respondents (4.3%) allowed free access without consent.

3.7 | Material tracking mechanisms

More than half of the respondents (30; 62.5%) reported that they have a tracking mechanism for plant material received and about half of the respondents have a tracking mechanism for plant material provided (24; 50%). The remaining respondents (15; 31.3%) do not have a tracking mechanism.

The majority of respondents indicated that electronic databases/spreadsheets were used as means of tracking material (30; 83.3%) and about half of the respondents also use IPEN numbers (20; 55.6%) and paper records (18; 50%) as a tracking mechanism. One respondent (2.8%) mentioned a document of recognition from the foreign organization as the means of tracking.

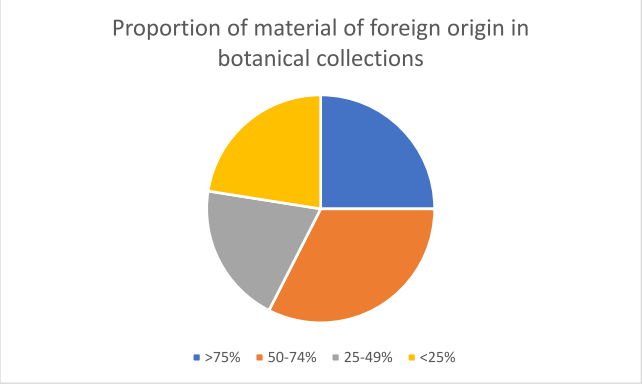

FIGURE 2 Proportion of plant material in plant collections that is of foreign origin ($n = 45$ botanical institutions).

3.8 | Types of benefits shared

The survey results showed that various types of benefits were shared with providers of plant material. The most frequently mentioned kinds of benefit shared were knowledge transfer (33; 75%) and participation in research (26; 59.1%). These were followed by joint authorship of publications (21; 47.7%), exchange of educational materials (20; 45.5%), access to research results (20; 45.5%), training/capacity building (17; 38.6%), and technical support for conservation (16; 36.4%). Some also mentioned funding/financial support (8; 18.2%), access to technology/facilities (7; 15.9%), and sharing other plant material in return (3; 6.8%). Four respondents (9.1%) reported that no benefits were shared with providers of plant material.

3.9 | Familiarity with the CBD and ABS instruments

Nineteen (40.4%) of the respondents were very familiar with the CBD, but nine (19.2%) respondents reported that they never heard of the CBD. Similar trends were found for the concept of ABS (32.6% very familiar; 26% not at all familiar) and with the Nagoya Protocol (46% very familiar; 8% not at all familiar).

In the case of the ITPGRFA, more than half of the respondents were very unfamiliar with the ITPGRFA (25; 52.08%) and only two (4.17%) were very familiar with the Treaty. Regarding the IPEN, about half of the respondents (24; 51.1%) were very familiar with IPEN and only six (12.8%) had never heard of IPEN.

Familiarity with CBD, ABS, Nagoya Protocol, and ITPGRFA was found to be not significantly correlated with regional categories (Spearman test, $p = 0.726$, 0.465, 0.410, 0.781, and 0.155) respectively at the 0.05 level. However, the frequency of plant material provided and received was found to be significantly correlated with IPEN familiarity (Spearman test, $p = 0.026$ and 0.005) at the 0.05 and 0.01 levels, respectively.

3.10 | Major constraints to the exchange of plant material

Nearly all the respondents indicated that there are major constraints to the international exchange of plant material (44; 91.7%), and the remaining respondents reported no major constraints (1; 2.1%) or they did not know (3; 6.2%).

The most frequently mentioned constraint to the international exchange of plant material was cumbersome bureaucratic procedures (37; 84.1%), followed by poor knowledge of compliance requirements (ABS, biosafety, CITES) (19; 43.2%), lack of national ABS regulations

and permitting systems (15; 34.1%), poor quality of data associated with collections (14; 31.8%), and lack of tracking mechanisms for shared material (10; 22.7%). Some also reported a lack of trust in compliance regulations in recipient countries/organizations (8; 18.2%) and poor-quality collections (5; 11.4%). Seven respondents (15.9%) also reported other constraints such as the CBD and Nagoya Protocol, which were mentioned by three of the seven respondents who offered comments. The remaining four mentioned under-resourced organizations and expertise, lack of interest, confusing regulations, and conflation of non-commercial botanical research with for-profit activities (Figure 3).

4 | DISCUSSION

4.1 | Extent of plant material exchange

Despite the huge need for collaboration between African and European institutions in research and development, the levels of plant material exchange via Index Seminum were found to be very low, and this was largely attributed to limited human and technological capacity in African institutions that restricted their involvement in research and development. This finding agrees with SCBD (2009), which indicated that there are serious gaps in capacity for ex situ conservation, especially in Africa, parts of Asia, the Caribbean, Latin America, and the Middle East. Thus, there is a need to address the gaps in capacity to strengthen collaboration between African and European botanical institutions.

The survey results indicated that those countries who provide the most material also receive the most material. Accordingly, Germany, Italy, and the USA were the most frequent recipients and provider countries. Similar patterns of proportionality between providers and recipients were also observed in the respondents' responses, in which about 45 of the respondents (81.8%) and 47 of the respondents (85.5%) indicated their institution provided and received plant material, respectively. This indicates that material exchange is a two-way process and there is interdependence among institutions.

Even though most of the respondents to the survey reported that their institutions were involved in plant material exchange, only about 30% of the respondents were able to indicate from which countries they received and to which country they provided material. This is likely due to poor documentation and tracking mechanisms.

4.2 | Mechanisms of plant material exchange

Several mechanisms were used to exchange plant materials, with most based on agreements and permits, some based on consent without an agreement, and a few without consent or agreements. Such variation in the mechanisms of plant material exchange is likely to be caused by different national and institutional policies, which increase the complexity of third-party transfer and wider networking and collaborations. This suggests a need to adopt standardized mechanisms that comply with the global ABS instruments in order to help to facilitate transfer of material and also develop trust.

4.3 | Tracking mechanisms

The main tracking mechanisms employed were electronic databases/spreadsheets, IPEN numbers, and paper records. This result differs from data provided by Davis et al. (2015) who reported that many gardens do not use the IPEN system as a tracking mechanism. National or institutional electronic databases and many other record systems are not suitable tracking mechanisms as they are not easily accessible to all actors. The present study also indicated that about 31.3% of the respondents' institutions do not have any mechanism for tracking, which leaves the material without information on its origin and associated ownership rights and benefits. It is obvious that such a situation will result in impediments to plant material exchange and will negatively affect collaboration among some institutions. It is also against the principles of the CBD, which recognizes the sovereign rights of states over their genetic resources (SCBD, 1993).

4.4 | Types of benefits shared

Knowledge transfer and participation in research, which were found to be the most frequently mentioned kinds of benefit shared

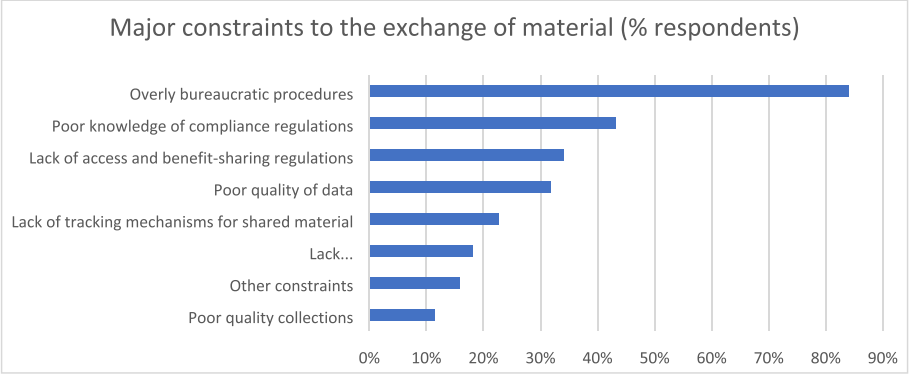

FIGURE 3 Major constraints to the exchange of plant material identified by respondents to a survey ($n = 48$ respondents). Identification of more than one constraint was permitted.

with providers of plant material, did not attract many low- and middle-income countries to become involved in collaborative research and development that involves plant material exchange. Thus, there is a need to promote the least frequently shared benefits, such as technical support for conservation, access to technology and facilities, training and capacity building, and funding or financial support.

4.5 | Familiarity with ABS instruments

The survey result showed that more than half of the respondents had never heard of the ITPGRFA, which established the multilateral ABS system. About a quarter of the respondents had no knowledge of their national ABS regulations, institutional ABS policies, or ABS principles. As the respondents are from institutions involved in plant material exchange it is alarming to find that so many had such little knowledge of ABS. This all indicates that improvements to the training of staff in PGR institutions are required.

4.6 | Major constraints

The results of the survey showed that cumbersome bureaucratic procedures are the major constraint to plant material exchange; however, these procedures are likely to be a consequence of the lack of tracking mechanisms for shared material and the lack of trust in compliance regulations being enforced in recipient countries/organizations. This result is in accord with Kamau et al. (2010) who reported lack of tracking mechanisms as one of the factors that have made provider countries particularly cautious and pushed them to adopt restrictive access conditions to their genetic resources. Thus, the key challenges to overcoming these constraints are the recognition and utilization of standardized exchange mechanisms with low bureaucratic burdens. By facilitating and securing the tracking of exchanged material, this will ultimately increase the effectiveness of and trust in these exchange processes.

AUTHOR CONTRIBUTION

Design of the research: Ayenew Ashenafi, Sebsebe Demissew, and Paul Smith; data analysis: Ayenew Ashenafi; draft preparation: Ayenew Ashenafi; review and editing: Ayenew Ashenafi, Sebsebe Demissew, Paul Smith, Ayenew Ashenafi, Michael Kiehn, and Feleke Woldeyes; supervision: Sebsebe Demissew.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest for this research.

DATA AVAILABILITY STATEMENT

The data are available from the corresponding author upon request.

ORCID

Ayenew Ashenafi https://orcid.org/0000-0002-1797-3744
Paul Smith https://orcid.org/0000-0003-1015-054X
Michael Kiehn https://orcid.org/0000-0002-0095-0618
Sebsebe Demissew https://orcid.org/0000-0002-0123-9596

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