INTRODUCED ORNAMENTAL PLANTS: DIVERSITY AND INVASION RISK IN ADDIS ABABA AND BISHOFTU, ETHIOPIA

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ABSTRACT: Invasive Alien Plant Species (IAPSs) pose serious threats to biodiversity and economies. Ornamental horticulture has been a major pathway for the of IAPSs introduction in Ethiopia. Despite this, limited attention has been given to the diversity and invasiveness potential of introduced ornamental plants in urban areas. Hence, this research aimed to study the diversity and potential invasiveness of introduced ornamental plant species in selected nursery sites of Addis Ababa and Bishoftu. An inventory survey was conducted across seven nursery sites, documenting 149 plant species representing 127 genera and 52 families. Of the total recorded species, 38 (25.5%) were identified as naturalized and Invasive Alien plant species. In addition, 26.77% of the documented genera and 36.54% of the recorded families contained invasive alien representatives. A one-way ANOVA, followed by Tukey's Honestly Significant Difference (HSD) test, was used to analyze the effects of introduced ornamental plant species (measured by percentage area coverage) on the richness of Invasive Alien Plant Species (IAPS). The analysis revealed a significant positive relationship, indicating that many introduced ornamentals possess considerable invasiveness potential within the study area. These findings highlight ornamental horticulture as a critical pathway for the introduction and spread of alien plant species. Consequently, raising public awareness about the origins and purposes of ornamental plant introductions, together with the implementation of effective biosecurity measures and management strategies, is essential to mitigate future threats to regional biodiversity.

Key words/phrases: Horticulture, Introductions, Invasive Alien Plant Species, Nursery Sites

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INTRODUCTION

The introduction of non-native plant species has become a major global concern, as many of these species have the potential to become invasive and disrupt native ecosystems (Allendorf and Lundquist, 2003). Ornamental plants, in particular, hold a significant share of introduced species, as they are often traded and planted for their aesthetic appeal (Virtue *et al*., 2008). The ornamental horticulture industry, which encompasses cultivation, production, and trade of flowers, ornamental plants, and landscaping products, is responsible for the introduction, propagation, and transport of thousands of nonnative plant species worldwide. While a majority of these introduced plant species remain confined to their intended locations or spread without causing significant environmental damage, some have proven to be remarkably invasive and pose a serious threat to native ecosystems (Pheloung *et al*., 1999; Niemiera and Holle, 2009).

The introduction of ornamental plants from distant lands has undoubtedly enriched our horticultural landscape. Species like tulips from Turkey, roses from China, and dahlias from Mexico have become integral parts of our gardens, adding a touch of exotic beauty to our surroundings (Gessert, 2010). However, the introduction of ornamental plants has also introduced a hidden threat: the potential for becoming invasive alien species (IAS). IASs are non-native species that have been introduced into a new environment and have the ability to spread aggressively, causing harm to native ecosystems and human livelihoods (Mooney *et al*., 2005). In other words, IAS are among today's most daunting environmental threats, costing billions of dollars in economic damages and wreaking havoc on ecosystems around the world.

Lantana camara L.is a prime example of an invasive alien species that was originally introduced for ornamental purposes worldwide but has since spread aggressively into natural ecosystems, causing significant ecological damage (Boy and Witt, 2013). Its ability to thrive in a variety of habitats, coupled with its prolific seed production and tolerance to various environmental conditions, has made it a challenging invader in many parts of the world. The species is a significant weed of which there are some 650 varieties in over 60 countries (GISD, 2023a). Similarly, *Eichhornia crassipes* (Mart.) Solms (water hyacinth), introduced as an aquatic ornamental plant, has become a formidable invader of waterways, choking rivers and lakes, and disrupting aquatic ecosystems in Ethiopia and elsewhere in the world (Rezene, 2005). Originally from South America, *E. crassipes* is one of the worst aquatic weeds in the world. It's beautiful, large purple and violet flowers make it a popular ornamental plant for ponds. It is now found in more than 50 countries on five continents (GISD, 2023b). Another example is the *Parthenium hysterophorus L.*(congress grass), native to tropical America. Introduced as an ornamental plant elsewhere, it has since become a notorious IAS, infesting vast tracts of land and causing significant economic losses in agriculture and livestock production. The species has been introduced into Ethiopia with contaminated cereal grain in the 1970's (Taye, 2002; Taye *et al.*, 2004; GISD, 2023c ;).

Invasive alien species (IAS) rank among the primary direct drivers of biodiversity loss. The detrimental effects of IAS on biodiversity stem from their competition with native species for resources, and introduction of pathogens. Additionally, they alter the composition and structure of ecosystems, diminishing the services these ecosystems provide. Beyond their environmental impact, IAS poses a threat to food security, human health, and economic activities.

The global trade in ornamental plants has inadvertently facilitated the introduction and spread of IAS into new environments. These non-native plants, often introduced for their aesthetic appeal, pose a significant threat to native biodiversity, ecosystem function, and economic productivity. Understanding the pathways, drivers and invasiveness of plants introduced through the ornamental plant trade is crucial for developing effective prevention and control strategies. Various studies have been conducted in Ethiopia on the distribution, impact and controlling and management methods of IAS (e.g.Shiferaw *et al*., 2004; Berhanu and Tesfaye, 2006; Shiferaw *et al*., 2021).

However, existing research on IAS in Ethiopia has focused on well-established and problematic species that already pose significant threats to the environment, biodiversity, and livelihoods. Accordingly, there is a lack of research on the potential invasiveness of newly introduced ornamental plants, which may eventually become serious invaders in the future. Therefore, the objective of this study was to identify potential invasive species among the introduced ornamental plant species in Addis Ababa, Bishoftu and surrounding areas. Consequently, we tested the hypothesis that a significant number of introduced ornamental plants have invasiveness potential in Ethiopia.

Materials and methods

Study Area

The study was conducted in Addis Ababa, the capital city of Ethiopia, and Bishoftu where the majority of ornamental plants are introduced, reproduced and distributed to users. Bishoftu Town, which is about 45kms south of Addis Ababa, is a major supplier of introduced and reproduced ornamental plants. Generally, seven study sites (five in Addis Ababa and two in Bishoftu) were purposely selected and investigated (Fig.1).

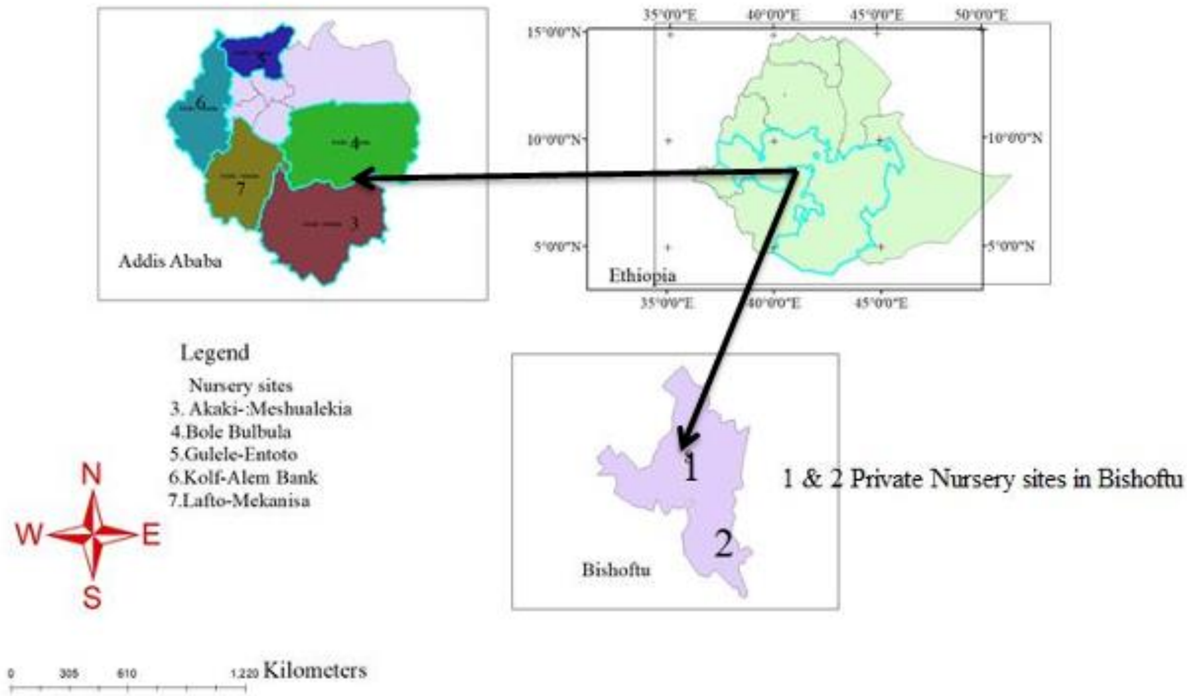

Figure 1. Map of Ethiopia showing the study sites (Addis Ababa and Bishoftu)

Data Collection

A detailed review of bibliography and online botanical databases was conducted prior to an extensive fieldwork and botanical identification. Direct field observations were combined with data obtained from the questionnaire survey with the local residents to identify introduction pathways and invasion history. Surveys in national databases and queries to global databases were conducted to determine the invasive alien ornamental plants.

An inventory of ornamental plant species was conducted in five and two nursery sites of Addis Ababa and Bishoftu, respectively. Systematic field surveys were conducted in the specified study sites to detect the presence of invasive alien ornamental plant species. Data on species name, genus, family, habit, use and impacts were collected. Photographs of each species in its current state were taken and archived.

A thorough review of scientific literature and comparative searches of online IAS databases such as Global Invasive Species Database (http://www.iucngisd.org/gisd) and CABI Compendium (https://www.cabidigitallibrary.org/journal/cabicompendium) was also conducted to gather information on introduced ornamental plant species in the study area and elsewhere.

Data on top five species of their weed history in other countries such as countries of origin and countries of introduction, impacts and pathways for the spread of propagules (dispersal mechanisms) were investigated based on established IAS databases and literature surveys.

Data Analysis

Established Weed Risk Assessment tools elsewhere such as the Weed Risk Assessment Protocol (WRAP) (Pheloung *et al*., 1999; Virtue *et al*., 2008; Conser *et al*., 2015) was used to evaluate the invasiveness potential of each introduced ornamental plant species. Data was analyzed using spreadsheet programs to prioritize potentially invasive alien species and identify patterns and relationships between ornamental plant introduction, invasion success, and potential ecological impacts.

For the constraints, specifically, the percentages (area coverage) of introduced ornamental plant species, the collected data were analyzed via a one-way Analysis of Variance (ANOVA) to test for statistically significant differences in the mean richness of Invasive Alien Plant Species (IAPS). Where the ANOVA indicated significant effects, post-hoc pairwise comparisons of treatment means were conducted using Tukey’s Honestly Significant Difference (HSD) test at a 5% significance level ($\alpha = 0.05$). This analysis identified which specific introduced ornamental plant species coverage/ percentage groups (0–25%, 26–50%, 51–75%, and 76–100%) differed significantly from one another.

Plant identification

Plants were identified onsite using plant identification tools, namely Pl@ntNet (Goëau *et al.*, 2014) using Northeast Tropical Africa and World Flora databases and at the National Herbarium (ETH). Plant specimens were collected, pressed and deposited at the Ethiopian Biodiversity Institute Herbarium. Accuracy of 70% and above of the Pl@ntNet identification tool were regarded as correct scientific names of the species (https://powo.science.kew.org/)

RESULTS

Richness of Introduced Ornamental Plant Species

A total of 149 plant species were identified in the study areas (Appendix 1). From the total identified plant species, 38 of them were naturalized and Invasive Alien Plant Species (IAPS) according to the Global Invasive Species Database (GISD); whereas 111 were non-invasive plant species. Regarding the reason for introduction of the identified IAPS, from the total identified IAPS, 31 (81.58%) of them were introduced primarily for ornamental purposes.

Other uses include medicine, timber, hedge, bee forage, fodder, nitrogen fixation, soil conservation, etc.; whereas seven species (18.42%) were introduced accidentally as a contaminant/weeds (*Alternanthera pungens* Kunt, *Argemone ochroleuca* Sweet, *Bidens pilosa* L, *Cuscuta campestris* Yunck and *Galinsoga parviflora* Flora Cav.) and two species (5.27%) were introduced for restoration and erosion control (*Acacia saligna* (Labill.) H.L.Wendl) and as edible fruit *(Psidium guajava* L.) (Table 1). *Lantana camara* is the most dominant and notorious IAS in the nursery sites and in most parts of the country.

Table 1. Lists of identified naturalized and IAPS during the investigation including reasons for their introduction and origin based on GISD and other sources (mentioned in the table below)

	Scientific name	Families	Reason for introduction	Origin/native to	Source
1.	*Acacia saligna* (Labill.) Wendl	Fabaceae	For restoration and erosion	Southwestern and Western Australia	(Witt and Luke, 2017).
2.	*Agave americana* L.	Agavaceae	For its fiber and ornamental	Mexico and southern USA	(Witt and Luke,2017)
3.	*Ageratum conyzoides* L.	Asteraceae	Accidentally as a contaminant/weed and ornament	Central and South America and West Indies.	(Witt and Luke,2017)
4.	*Ageratum houstonianum* Mill.	Asteraceae	Accidentally as a contaminant/weed and ornament	Central and South America and West Indies	(Witt and Luke,2017)
5.	*Alternanthera pungens* Kunth.	Amaranthaceae	Accidentally as a contaminant/weed	Tropical America	(Kuma *et al.*,2021)
6.	*Argemone ochroleuca* Sweet	Papaveraceae	Accidentally as a contaminant	Mexico and West Indies	(Witt and Luke ,2017)
7.	*Azadirachta indica* A.Juss.	Meliaceae	For restoration and ornament.	Bangladesh, India, Malaysia and Myanmar	(Witt and Luke, 2017).
8.	*Bidens pilosa* L.	Asteraceae	Accidentally as a contaminant/weed	Tropical America, specifically Mexico, central America, the Caribbean and parts of south America	(Mekonnen *et al*.,2018)
9.	*Caesalpinia decapetala*(Roth) Alston	Fabaceae	For bee forage and ornament.	Tropical and subtropical Asia.	(Witt and Luke, 2017).
10.	*Casuarina cunninghamiana* Miq.	Casuarinaceae	For timber and ornament	Australia.	(Witt and Luke,2017)
11.	*Casuarina equisetifolia* L.	Casuarinaceae	For timber and ornament.	Australia	(Witt and Luke, 2017).
12.	*Catharanthus roseus (L.) G. Don*	Apocynaceae	For medicine and ornament	Madagascar	(Witt and Luke, 2017).
13.	*Cuscuta campestris* Yunck.	Convolvulacee	Accidentally as a contaminant /weed	Bahamas, Canada, Cuba, Guadeloupe, Jamaica, Martinique, Mexico and USA.	(Witt and Luke, 2017).
14.	*Datura stramonium* L.	Solanaceae	Ornament and accidentally as a contaminant	Tropical North America	(Witt and Luke, 2017).
15.	*Delonix regia* (Hook.) Raf.	Fabaceae	Ornamental	Madagascar.	(Witt and Luke, 2017).
16.	*Dovyalis caffra* (Hook.f. & Harv.) Sim	Salicaceae	Hedge and ornament.	Mozambique, South Africa, Swaziland and Zimbabwe	(Witt and Luke, 2017).
17.	*Duranta erecta* L.	Verbenaceae	Hedge/barrier and ornament.	Tropical America, Mexico, the Caribbean, enteral and south America	(Witt and Luke, 2017).

18.	*Galinsoga parviflora Cav.*	Asteraceae	as a contaminant /weed	South America	(Mekonnen *et al.*,2018)
19.	*Grevillea robusta* A. Cunn. ex R. Br.	Proteaceae	Timber, bee forage, and ornament	Australia	(Witt and Luke, 2017).
20.	*Helianthus annuus* L.	Asteraceae	Accidentally as a contaminant.	Mexico and USA.	(Witt and Luke,2017)
21.	*Ipomoea purpurea* (L.) Roth	Convolvulaceae	Ornament	South America and Mexico	(Witt and Luke,2017)
22.	*Jacaranda mimosifolia* D. Don	Bignoniaceae	Timber, shade and ornament	Argentina and Bolivia	(Witt and Luke,2017)
23.	*Lantana camara* L.	Verbenaceae	Hedging/barrier and ornament	Colombia, Costa Rica, Cuba,Jamaica, Mexico and Venezuela	(Witt and Luke, 2017).
24.	*Leucaena leucocephala* (Lam.) de Wit	Fabaceae	Fodder, nitrogen fixation, soil conservation, and ornament	Belize, Guatemala and Mexico	(Witt and Luke, 2017).
25.	*Melia azedarach* L.	Meliacea	Timber, medicine, shade and Ornament.	Australia, China, India, Indonesia, Japan, and Sri Lanka.	(Witt and Luke, 2017).
26.	*Mimosa pigra* L.	Fabaceae	Nitrogen fixation, medicine, hedge and ornament.	Tropical America ,Mexico, northern Argentina and central America	(Witt and Luke,2017)
27	*Mirabilis jalapa* L.	Nyctaginaceae	Ornament	Peru	(Witt and Luke,2017)
28.	*Nicotiana glauca* Graham	Solanaceae	Medicine, insecticide and ornament	Argentina, Brazil, Bolivia, Chile, Ecuador, Paraguay, Peru and Uruguay	(Witt and Luke, 2017).
29.	*Parkinsonia aculeata* L.	Fabaceae	Hedge. shade and ornament	Argentina, Bolivia, Galápagos Islands, Paraguay, Peru and Uruguay.	(Witt and Luke, 2017).
30.	*Parthenium hysterophorus* L.	Asteraceae	Medicine, ornament and accidentally as a contaminant/weed	Argentina, Bolivia, Cuba, Guatemala, Haiti, Jamaica, Mexico, Paraguay, Uruguay, Venezuela and Virgin Islands.	(Witt and Luke, 2017).
31.	*Pinus patula Schiede* ex Schltdl. & Cham.	Pinaceae	Timber, paper, pulp production and ornament	Mexico	(Witt and Luke,2017)
32.	*Psidium guajava* L.	Myrtaceae	Edible fruit.	Argentina, Bolivia, Brazil, Colombia, Ecuador, Mexico, Paraguay, Peru, Venezuela and the Caribbean.	(Witt and Luke,2017)
33.	*Ricinus communis* L.	Euphorbiaceae	Castor oil and ornament	Uncertain; from multiple Sources of introduction.	(Witt and Luke,2017
34.	*Salvia coccinea* Buc'hoz ex Etl.	Lamiaceae	Ornament.	Brazil, Colombia, El Salvador, Guatemala, Mexico,	(Witt and Luke, 2017).

				Peru, southeastern USA ,and Caribbean	
35.	*Salvia leucantha* Cav.	Lamiaceae	Ornament.	Mexico and possibly elsewhere in Central America	(Witt and Luke, 2017).
36.	*Salvia tiliifolia* Vahl.	Lamiaceae	Accidentally as a contaminant and as ornamental plant	Mesoamerica (Mexico, central America and northern south America)	(Friis,2006)
37.	*Senna didymobotrya (Fresen.)* H.S. Irwin & Barneby	Fabaceae	introduced elsewhere for medicine and Ornament	Tropical Africa	(Witt and Luke,2017)
38.	*Verbesina encelioides(*Cav.) Benth. & Hook. f.	Asteraceae	Ornament and accidentally as a contaminant/weed	Mexico and USA.	(Witt and Luke, 2017).

The highest plant species richness was recorded in Entoto and Denbi nursery sites (richness = 37), followed by Bole Bulbula (richness = 35) and Akaki-Meshualekia nursery sites (Richness = 30). Conversely, the smallest plant species richness was documented in Mekanisa (Richness = 22) followed by Alem Bank nursery sites (richness = 24). The outcomes of this study also revealed significant variations in the richness of IAPS across different nursery sites. The highest IAPS richness was recorded in Entoto nursery site (richness = 19), followed by Denbi (richness = 16). Conversely, the smallest IAPS richness was documented in Mekanisa nursery site (Richness = 7) followed by Gadiku areas (richness = 8) (Fig 2).

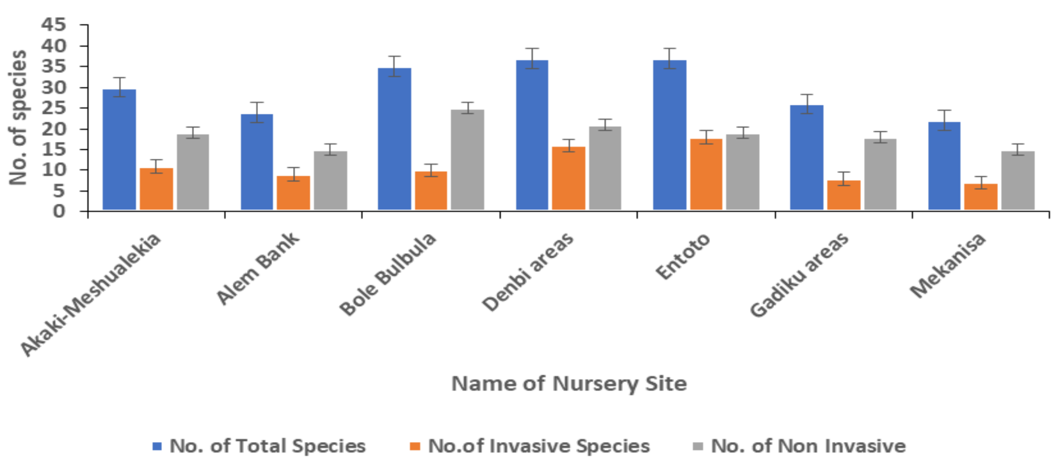

Figure 2. Number of invasive alien and non-invasive plant species in each nursery site

Plant species composition

A total of 149 plant species belonging to 127 genera and 52 families were documented from the study areas (Fig.3). From the total identified plant species, 38 (25.5%) of them were IAPS. Besides, from the total identified genera, 26.77% of them were IAPS. Regarding the families identified during the study, 36.54% of them were IAPS (Table 2).

Table 2. Proportion of IAOPS and invasive alien weeds species, genus and families to all identified plant species during the study

	Taxonomic unit	Proportion of IAS to all (%)
1.	Species	25.5
2.	Genus	26.77
3.	Family	36.54

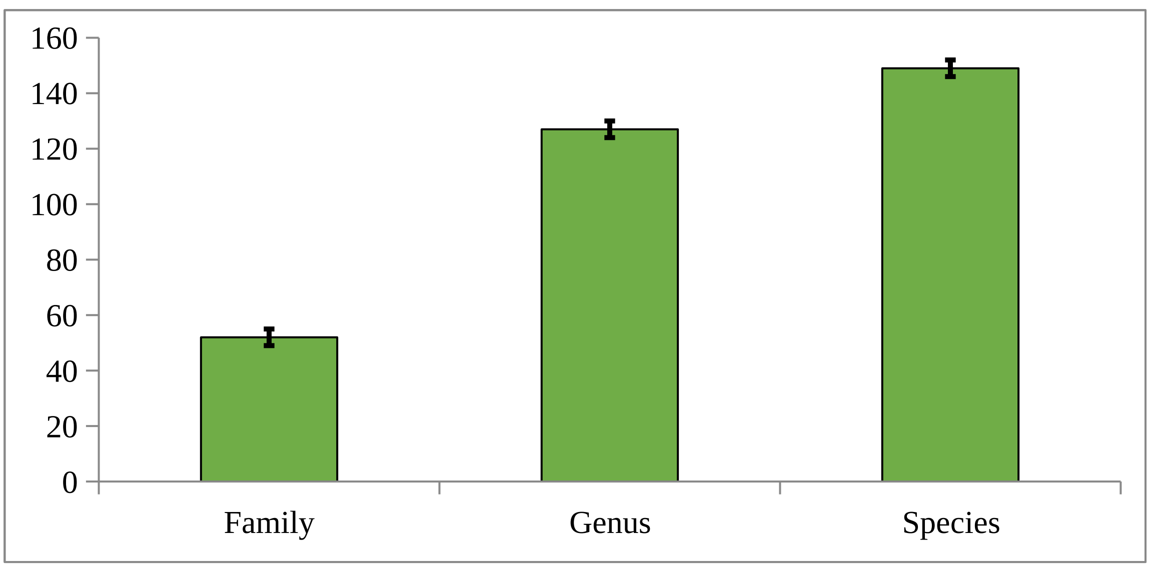

Figure 3. Total number of family, genus and species of the identified plant species

Moreover, a total of 38 IAPS belonging to 34 genera and 19 families (Fig. 4) and 111 non-invasive plant species belonging to 43 families were identified (Appendix 1)

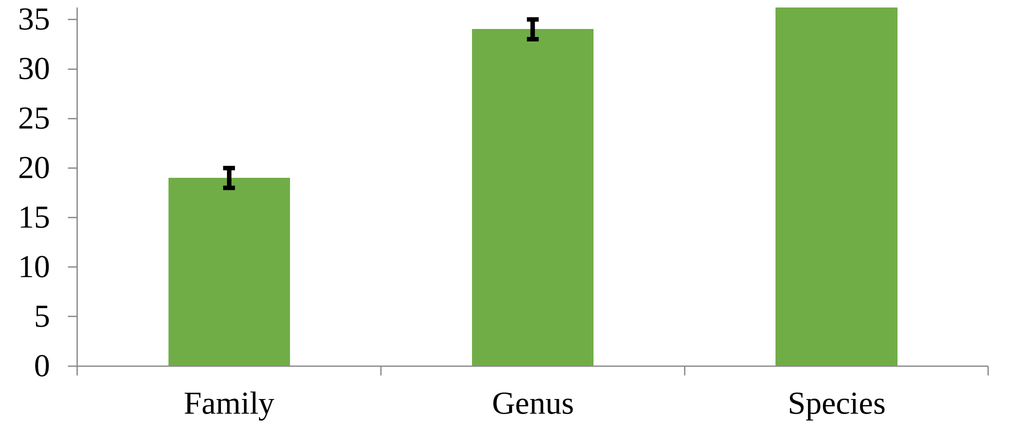

Figure 4. Total number of family, genus and species of the identified IAPS

The most dominant IAPS belong to the families Asteraceae and Fabaceae, where each family contributed seven species (18.42%); followed by Lamiaceae, which contributed three species (7.89%) (Fig. 5).

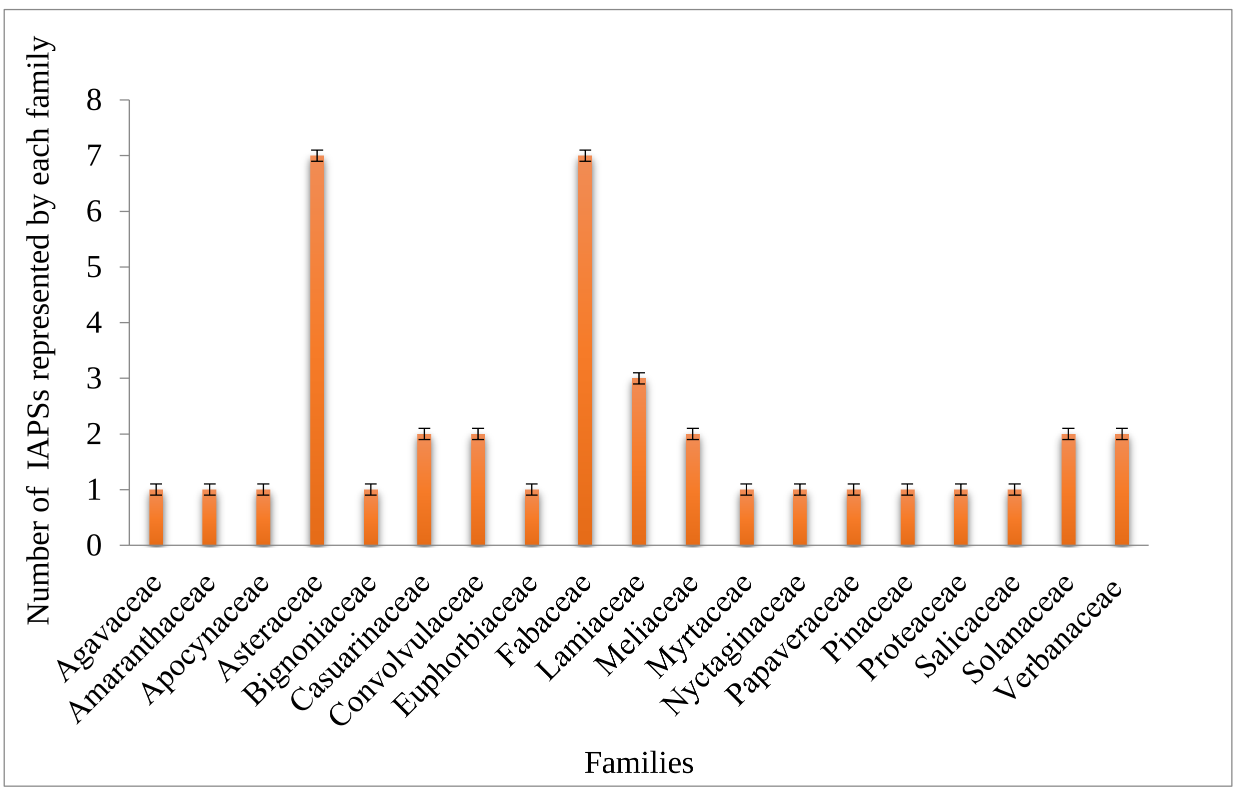

Figure 5. Number of Invasive Alien Plant Species in each Family

Habit Distribution of Invasive Alien Plant species (IAPS)

The composition in habit of IAPS showed that the identified species were herbs, shrubs, trees and liana. The majority of the species were herbs followed by shrubs in most of the nursery sites (Fig. 6).

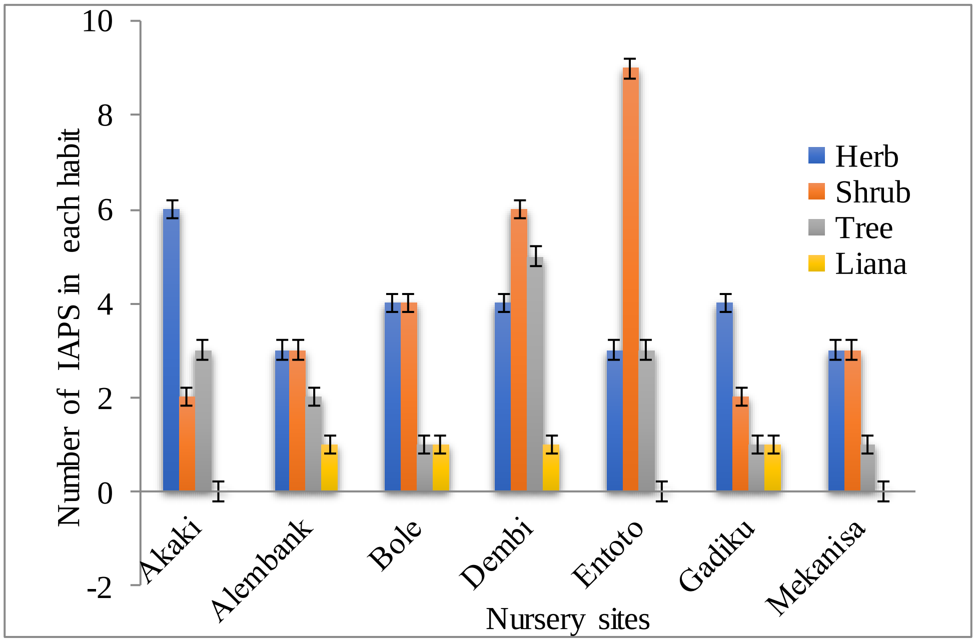

Figure 6. The composition in habit of IAPS in the study areas

Moreover, the composition in habit of all plant species, the majority of the species were herbs followed by shrubs in the study areas (Fig. 7).

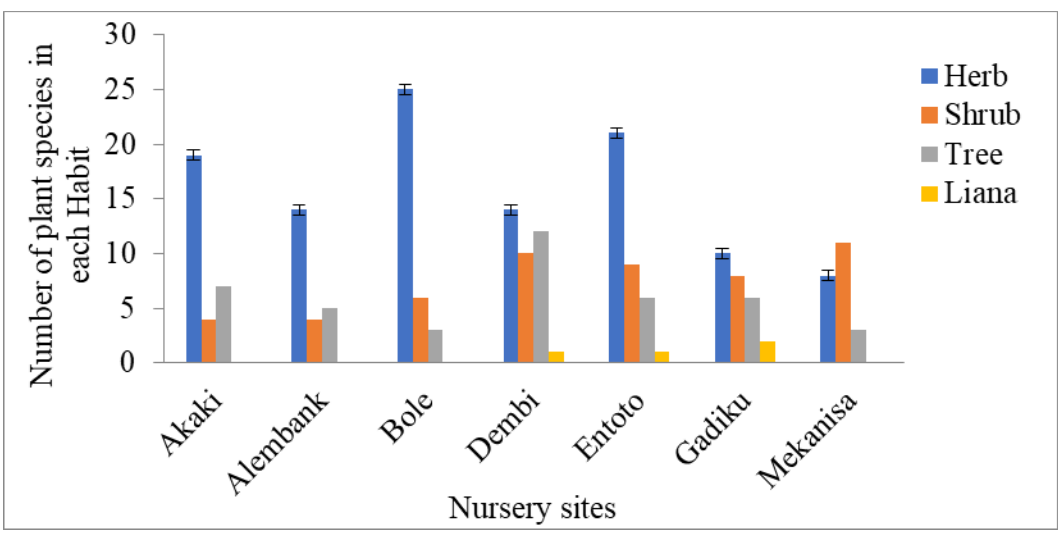

Figure 7. The composition in habit of all plant species in the study areas

Potential and actual uses of Invasive Alien Plant Species (IAPS)

The majority (81.58%) of the identified Invasive Alien Plant Species (IAPS) were used as ornamental plants and other multipurpose uses such as construction, soil conservation, fencing, shade, firewood, afforestation, oil production, etc. On the other hand, 13.15% of them were invasive alien weeds with no other known uses and 5.27% were used as soil conservation and afforestation purposes (e.g. *Acacia saligna)* and edible fruit (e.g. *Psidium guajava*).

One-Way Analysis of Variance on Percentage of Introduced Ornamental Plant Species versus Richness of Invasive Alien Plant Species (IAPS)

The findings of the study demonstrated a positive correlation between the percentage of introduced ornamental plant species and the richness of Invasive Alien Plant Species (IAPSs) (Fig.8). In general, IAPS richness increased concomitantly with greater land area coverage by introduced ornamental plants. Consequently, the highest mean IAPS richness was recorded in the maximum coverage category (76–100%), with a value of 22 ± 2.47. This was followed by the 51–75% coverage category, which exhibited a mean richness of 16.29 ≈ 16. In contrast, the lowest mean IAPS richness was observed in the lowest coverage category (0–25%), with a value of 6.67 ≈ 7 ± 1.59.Thus, compared to the high-coverage areas (76–100%), the mean IAPS richness in low-coverage areas (0–25%) was reduced by 68.18% (Table 3). These results indicated that introduced ornamental plant species possess a high potential for facilitating invasiveness.

Table 3. Invasiveness Potential of Introduced Ornamental Plant Species

Percentage(coverage) of introduced ornamental plant Species	N	Mean number of IAPSs	Std. Deviation	Std. Error	95% Confidence Interval for Mean	
					Lower Bound	Upper Bound
0-25%	21	6.67	1.592	0.347	5.94	7.39
26-50%	21	11.81	1.990	0.434	10.90	12.72

51-75%		21	16.29	1.793	0.391	15.47	17.10
76-100%		21	22.00	2.470	0.539	20.88	23.12
Total		84	14.19	6.009	0.656	12.89	15.49
Model	Fixed Effects			1.988	0.217	13.76	14.62
	Random Effects				3.262	3.81	24.57

The analysis demonstrated statistically significant differences in the mean richness of Invasive Alien Plant Species (IAPS) across the gradient of area coverage by introduced ornamental plants. The highest mean IAPS richness was associated with the greatest coverage level (76–100%). A one-way Analysis of Variance (ANOVA) confirmed that IAPS richness varied significantly among the different percentage coverage categories (Table 4).

Table 4. One-way ANOVA on the number of IAPSs across the given Percentage (coverage) of Ornamental Plant Species

	df	Mean Square	F	Sig.
Between Groups	3	893.587	226.088	0.000
Within Groups	80	3.952		
Total	83			

Based on a one-way Analysis of Variance (ANOVA), significant variation was observed in Invasive Alien Plant Species (IAPS) richness across the gradient of introduced ornamental plant species coverage. Subsequent post-hoc analysis using Tukey's Honestly Significant Difference (HSD) Test confirmed that the percentage of area coverage (0–25%, 26–50%, 51–75%, and 76–100%) exerted a statistically significant impact on IAPS richness. Consequently, pairwise comparisons revealed that IAPS richness differed significantly ($p \leq 0.0001$) between all four coverage categories. These results demonstrate that IAPS richness is highly dependent upon the extent of introduced ornamental plant coverage, with a pronounced increase in IAPS diversity corresponding to progression from low to high percentage coverage (Table 5).

Table 5. Tukey's Honestly Significant Difference (HSD) Test to compare the variation in the Richness of IAPS among the various percentage (coverage) of introduced ornamental plant species

(I)Percentage of introduced ornamental plant species	(J)Percentage of introduced ornamental plant species	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
0-25%	26-50%	-5.143*	0.614	0.000	-6.75	-3.53
	51-75%	-9.619*	0.614	0.000	-11.23	-8.01
	76-100%	-15.333*	0.614	0.000	-16.94	-13.72
26-50%	0-25%	5.143*	0.614	0.000	3.53	6.75
	51-75%	-4.476*	0.614	0.000	-6.09	-2.87
	76-100%	-10.190*	0.614	0.000	-11.80	-8.58
51-75%	0-25%	9.619*	0.614	0.000	8.01	11.23
	26-50%	4.476*	0.614	0.000	2.87	6.09
	76-100%	-5.714*	0.614	0.000	-7.32	-4.10
76-100%	0-25%	15.333*	0.614	0.000	13.72	16.94
	26-50%	10.190*	0.614	0.000	8.58	11.80
	51-75%	5.714*	0.614	0.000	4.10	7.32

*. The mean difference is significant at the 0.05 level.

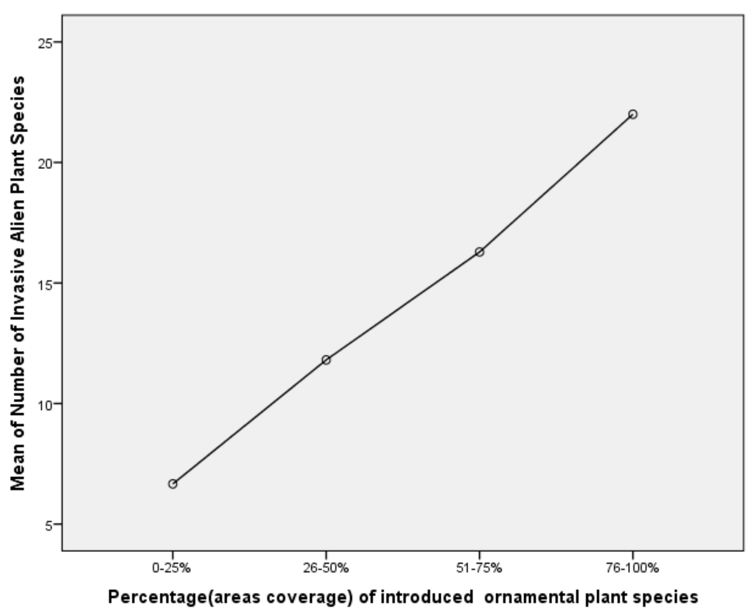

Figure 8. The relationship between percentages (area coverage's) of introduced ornamental plant species and richness of Invasive Alien Plant Species (IAPSs)

Potential Impacts of Invasive Alien Plant Species (IAPS) in the study areas

Based on the outcomes of this study, IAPS have been identified as one of the causes for the loss of biological diversity, ecosystem services degradation and economic damage in the study areas. From the identified IAPS, 36.84% of them had high and very high impacts on biodiversity of the nursery sites and the surrounding areas; whereas the remaining (63.16%) had medium impacts (Table 6).

Table 6. Impacts and levels of the impacts of naturalized and IAPS

	Scientific name	Impacts	Impacts Levels
1	*Acacia saligna* (Labill.) Wendl	Biodiversity	Medium
2	*Agave americana* L.	Biodiversity	Medium
3	*Ageratum conyzoides* L.	Farm, weed	Very high
4	*Ageratum houstonianum* Mill.	Biodiversity	High
5	*Alternanthera pungens* Kunth.	Farm, biodiversity	High
6	*Argemone ochroleuca* Sweet	Farm, biodiversity	Very high
7	*Azadirachta indica* A.Juss.	Biodiversity	Medium
8	*Bidens pilosa* L.	Farm	High
9	*Caesalpinia decapetala*(Roth) Alston	Road, biodiversity	High
10	*Casuarina cunninghamiana* Miq.	Biodiversity	Medium
11	*Casuarina equisetifolia* L.	Biodiversity	Medium
12	*Catharanthus roseus* (L.) G. Don	Biodiversity	Medium
13	*Cuscuta campestris* Yunck.	Farm, biodiversity	Very high
14	*Datura stramonium* L.	Biodiversity	Medium
15	*Delonix regia* (Hook.) Raf.	Biodiversity	Medium
16	*Dovyalis caffra* (Hook.f. & Harv.) *Sim*	Biodiversity	High
17	*Duranta erecta* L.	Biodiversity	High
18	*Galinsoga parviflora* Cav.	Biodiversity	High
19	*Grevillea robusta* A. Cunn. ex R. Br.	Biodiversity	Medium
20	*Helianthus annuus* L.	Biodiversity	Medium
21	*Ipomoea purpurea* (L.) Roth	Farm, biodiversity	Medium
22	*Jacaranda mimosifolia* D. Don	Biodiversity	Medium
23	*Lantana camara* L.	Farm, road, biodiversity	Very high

24	*Leucaena leucocephala* (Lam.) de Wit	Biodiversity	Medium
25	*Melia azedarach* L.	Biodiversity	Medium
26	*Mimosa pigra* L.	Biodiversity;	Medium
27	*Mirabilis jalapa* L.	Farm;road; biodiversity	Medium
28	*Nicotiana glauca* Graham	Biodiversity;	High
29	*Parkinsonia aculeata* L.	biodiversity	Medium
30	*Parthenium hysterophorus* L.	Farm, biodiversity	Very high
31	*Pinus patula Schiede* ex Schltdl. & Cham.	Biodiversity	Medium
32	*Psidium guajava* L.	Biodiversity	Medium
33	*Ricinus communis* L.	Biodiversity	Medium
34	*Salvia coccinea* Buc'hoz ex Etl.	Biodiversity	Medium
35	*Salvia leucantha* Cav.	Biodiversity	Medium
36	*Salvia tiliifolia* Vahl.	Farm, road, biodiversity	High
37	*Senna didymobotrya (*Fresen.) H.S. Irwin & Barneby	Farm; road; biodiversity	Medium
38	*Verbesina encelioides*(Cav.) Benth. & Hook. f.	Biodiversity, farm	High

DISCUSSION

The results of the study indicated that from the total identified IAPS, the majority were Invasive alien ornamental plant species (IAOPS) based on the Global Invasive Species Database (Witt and Luke, 2017). This indicated that ornamental horticulture is the major pathway for the introduction of IAPS. In agreement with our finding, the results of the study by Mayer *et al*. (2017) indicated that, from the identified 1268 ornamental garden plant species, 75% of them were alien to Germany. The study by Sirbu *et al*. (2022) also indicated that 25% of the recorded species were introduced intentionally for ornamental purposes. The findings of the investigation by Oduor *et al.* (2023) also confirmed that ornamental horticulture constitutes a major pathway of alien plant species introductions into different biogeographic regions. In addition, in line with our findings, the study by Raicu *et al*. (2024) showed that ornamental horticulture has significantly contributed to the proliferation of plant invasions on a worldwide scale.

In agreement with the finding of our study, the investigation by Drew *et al*. (2010) also confirmed that the horticulture industry, particularly ornamental horticulture, is deliberated as an essential pathway for introducing and spreading IAPS. The findings of the study by Silva *et al*. (2024) indicated that ornamental horticulture is known as an essential passageway for introducing IAPS into new habitats. Therefore, Ornamental plants have been escaping from cultivated environments for centuries, and human activities are considered serious factors in the invasion process, as they facilitate the spread of species outside their native habitats.

The most dominant IAPS families were Asteraceae and Fabaceae. In agreement with the findings of our investigation, the results of a study by Zhang *et al*. (2021) showed that species in the Asteraceae and Fabaceae families had a high dominance among alien, naturalized, and invasive species.

Regarding the habit of all plant species (IAPS and non-invasive plant species), the majority of the species were herbs, followed by shrubs in most of the nursery sites. This might be because herbs produce a large number of seeds and possess greater genetic flexibility and evolutionary rates. In addition, herbs are characterized by high growth rates due to their short life cycle and fast pollen grain and seed dispersal rates. They also occur in places where the weather conditions are not good for most plants (Belbase and Ghimire, 2021). In terms of growth form, herbaceous species played a greater role in promoting homogenization, followed by shrubs and trees (Dar and Resh, 2015).

As to the potential uses of the identified IAPS in our study, they were used for ornamental purposes, construction, soil conservation, afforestation, furniture production, etc. In agreement with our finding, the study by Witt *et al*. (2018) indicated that most plant species were intentionally introduced and are now cultivated and utilized for various purposes. Their study indicated that the majority of IAPS (46%) were grown as ornamentals or used as barriers/hedges (15%), for soil conservation, and as agricultural crops. In line with our finding, the study by Onozuka and Osawa (2022) indicated that *Agave americana L.*, an IAPS, had high ornamental value. The finding of the study by Bayón and Vilà (2019) confirmed that as the number of invasive ornamentals is very high, resources are limited to manage them all in the same way and it is necessary to create prioritization lists of plant species. Therefore, there is a need to identify those that are invasive and regulate their use for commercial and other purposes to reduce the risk of causing numerous impacts on the environment and biodiversity (Dehnen-Schmutz, 2011).

Rojas-Sandoval and Ackerman (2021) found that considerably more IAPS (54%) were intentionally introduced for ornamental purposes than for any other reasons in the Caribbean. Their results showed that hosted ornamental plants are effectively invading most important habitats across the Caribbean, deteriorating ecosystem services and threatening native biodiversity. The ornamental horticulture industry has the potential to foster the invasion process. The introduction of large numbers of non-indigenous species is one of the most important factors that contribute to an area being invaded (Von-Holle and Simberloff, 2005).

Moreover, several other studies carried out in this field of research, including Meyerson *et al*. (2005); Roberts *et al*. (2015); CABI (2016); Paini *et al*. (2016); Lone *et al*. (2019); Rai and Singh (2020); Syliver *et al*. (2020); Waghmode (2022); Najberek *et al*. (2024) support our findings. From the identified 38 IAPSs, the top five were selected, and their families, countries of origin, their impacts, and means of spread were discussed below based on established IAS databases and literature surveys. These are *Parthenium hysterophorus*, *Lantana camara*, *Argemone ochroleuca*, *Ageratum conyzoides*, and *Nicotiana glauca*.

Parthenium hysterophorus is a herbaceous IAPS of the Asteraceae family with common names like carrot weed, famine weed, or Congress grass. *P. hysterophorus* is native to Central and South America. It has been introduced to Ethiopia and East Africa for different reasons, such as medicine, ornament, and accidentally as a contaminant. In Ethiopia, it was regarded to be introduced accidentally through aid shipments or from Somalia during the Ethio-Somali War in 1976/77. It has now spread to almost every part of the country (Witt and Luke, 2017). *P. hysterophorus* is the most dangerous to natural biodiversity, flora, fauna and human health. It disrupts the ecology of grasslands, invades woodlands, and generally disturbs native vegetation through aggressive competition (Rwomushana *et al*., 2019). Being allelopathic, it inhibits the germination and growth of other plants, reducing crop yields and displacing palatable species in natural and improved pastures. It is one of the fastest spreading invasive plants, via different mechanisms ’such as water, animals, wind, agricultural materials, and transportation, occupying millions of hectares in Ethiopia (Evans, 1997).

Lantana camara is one of the worst IAOPS worldwide. It is an evergreen perennial shrub in the family Verbenaceae (Gooden et al., 2009). It is native to tropical and subtropical America. *L. camara* has usually been deliberately introduced into various localities in Ethiopia as an ornamental shrub. The distribution of *L. camara* in Ethiopia is very wide, and many ecosystems are affected by this species, including most nursery sites (Witt and Luke, 2017). About half of its flowers produce seeds. Mature plants can produce up to 12,000 seeds per plant every year. Seeds are believed to remain viable for several years under natural conditions (Nel, 2015). Its spread is stimulated by animal activities and human disturbances, such as cultivation and road construction (Sharma *et al*., 2005). *L. camara* has been categorized as the uppermost impacting IAOPS. It is a major threat to biodiversity and ecosystem services. Its impact is noticeable because of the species' invasive characteristics, such as fire tolerance, high seed production, allelopathy, high percentage fruit set, rapid vegetative growth, aggressive competitive ability, and proliferation throughout the year in ideal environmental conditions (Nel, 2015; Kumar *et al*., 2016).

Argemone ochroleuca is the other worst IAPS, which is native to Mexico and the West Indies. Common names: Devil's figs, Mexican prickle poppy, Mexican thistle, and white thistle (English) belongs to the family Papaveraceae (Patel, 2013; Witt and Luke, 2017). It reproduces by producing a large number of seeds, which may fall naturally to the ground. The majority of seed is dispersed by flood (Malik and Grover, 1973). *A. ochroleuca* has commonly been introduced into numerous localities in Ethiopia and East Africa accidentally as a contaminant (Witt and Luke, 2017). It is capable of adapting and even displacing the native flora. *A. ochroleuca* has been often confused with *A. mexicana* by their close biological link because they share similar phenotypic characteristics (Haisova and Slavik, 1975).

Ageratum conyzoides is one of the most widely adaptive weeds in Ethiopia in the family Asteraceae. *A. conyzoides* is native to tropical America. It has spread worldwide in the tropical and subtropical areas. It is an annual aromatic herbaceous plant (Dogra *et al*. 2009). *A. conyzoides* produces more than 40,000 seeds from a single plant. These seeds are easily dispersed into wide areas by wind and water, which will help in their establishment in a wide range of climatic conditions (Kohli *et al*., 2006). *A. conyzoides* has generally been introduced into different areas in Ethiopia and East Africa accidentally as a contaminant and ornamental plant. It has invaded predominantly in the grasslands, agricultural fields, forests, wastelands, plantations, natural pastures, riparian areas, lowlands, nursery sites, coastal dunes, and horticultural fields. It is a main threat to biodiversity, agriculture and ecosystem services (Witt and Luke, 2017).

Nicotiana glauca L, in the family Solanaceae, is the other IAOPS worldwide. It is native to South America. *N. glauca* has largely been introduced into different areas in Ethiopia and East Africa as medicine, insecticide, and an ornamental plant. It is invasive in Ethiopia and East Africa (Henderson, 2002). In Ethiopia, *N. glauca* grows in a wide variety of open and disturbed habitats, including roadsides, abandoned and disturbed land, nursery sites, and lakeshores. It is mainly a problem in relatively dry areas. Its overall negative impacts are ecosystem alteration, agricultural damage, and economic burden (Witt and Luke, 2017). *N. glauca* poses a threat to biodiversity by competing with native species for resources. All parts of the plant are poisonous (Brandes, 2000).Therefore, these and others introduced ornamental plant species had substantial invasiveness potential in Ethiopia.

CONCLUSION AND RECOMMENDATION

The results of this study indicated that a significant proportion of the introduced ornamental plant species possess a high potential for invasiveness within the study area. Statistical analysis via one-way ANOVA, followed by Tukey's Honestly Significant Difference (HSD) test, revealed a significant positive relationship between the proportional coverage of introduced ornamental plants and Invasive Alien Plant Species (IAPS) richness. This correlation confirms that numerous introduced ornamentals exhibit considerable invasive potential. Consequently, the ornamental horticulture industry is implicated as a primary vector for the introduction, propagation, and dissemination of numerous non-native species. These introduced ornamental plant species have demonstrated pronounced invasiveness and are environmentally detrimental. A comprehensive understanding of introduced ornamental plant species diversity and composition is therefore essential for interpreting current invasion trends, assessing and forecasting impacts on biodiversity and economy, and informing effective biosecurity policy. While the role of ornamental plants in biological invasions is substantial, it is acknowledged that they provide significant economic and aesthetic value. Thus, reconciling the trade in ornamental species with conservation imperatives is critical for sustainable biodiversity management. It is recommended that integrated management and prevention strategies be implemented, including: pre-introduction risk assessment and screening; public awareness campaigns; support for the identification of problematic Invasive Alien Ornamental Plant Species(IAOPS); regulatory measures, such as restrictions on the sale and transport of invasive alien species and the promotion of native or non-invasive alternatives to replace invasive ornamentals plant species.

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Appendix 1

List of plant species identified during the study including their families

No.	Scientific name	Family
1	*Acacia abyssinica* Hochst.	Fabaceae
2	*Acacia mearnsii* De Wild.	Fabaceae
3	*Acacia melanoxylon* R. Br.	Fabaceae
4	*Acacia saligna* (Labill.) Wendl.	Fabaceae
5	*Aeonium leucoblepharum* A. Rich.	Crassulaceae
6	*Agave americana* L.	Agavaceae
7	*Ageratum conyzoides* L.	Asteraceae
8	*Ageratum houstonianum* Mill.	Asteraceae
9	*Allophylus abyssinicus* (Hochst.)	Sapindaceae
10	*Alternanthera pungens* Kunth.	Amaranthaceae
11	*Amaranthus palmeri S. Wats.*	Amaranthaceae
12	*Amaranthus sparganiocephalus* Thell.	Amaranthaceae
13	*Amaranthus spinosus* L.	Amaranthaceae
14	*Amaranthus thunbergii* Moq.	Amaranthaceae
15	*Argemone ochroleuca* Sweet.	Papaveraceae
16	*Artemisia annua* L.	Asteraceae
17	*Artemisia rehan* Chiov.	Asteraceae
18	*Azadirachta indica* A. Juss.	Meliaceae
19	*Begonia cucullata* Willd.	Begoniaceae
20	*Bidens pilosa* L.	Asteraceae
21	*Caesalpinia decapetala*(Roth) Alston	Fabaceae
22	*Melaleuca citrina*(Curtis)Dum.Cours	Myrtaceae
23	*Callistemon rigidus* R.Br.	Myrtaceae
24	*Callistephus chinensis*(L.)Less.	Asteraceae
25	*Carica papaya* L.	Caricaceae
26	*Carpobrotus edulis* (L.) L. Bolus	Mesembryanthemaceae

27	*Casuarina cunninghamiana* Miq.	Casuarinaceae
28	*Casuarina equisetifolia* L.	Casuarinaceae
29	*Catharanthus roseus* L.	Apocynaceae
30	*Cenchrus setaceus*(Forssk)	Poaceae
31	*Chlorophytum comosum* (Thunb.) Jacques	Asparagaceae
32	*Citrus limon* L.	Rutaceae
33	*Codiaeum variegatum*	Euphorbiaceae
34	*Coffea arabica* L.	Rubiaceae
35	*Coleus scutellarioides* (L.)	Lamiaceae
36	*Colocasia esculenta* (L.)	Araceae
37	*Cordia africana* Lam.	Boraginaceae
38	*Cordyline fruticosa*(L.)	Asparagaceae
39	*Coreopsis grandiflora* Hogg ex Sweet	Asteraceae
40	*Coreopsis lanceolta* L.	Asteraceae
41	*Crinum asiaticum* L.	Amaryllidaceae
42	*Crocosmia crocosmiiflora* (Montbretia) - FSUS	Iridaceae
43	*Cuphea hyssopifolia* Kunth	Lythraceae
44	*Cuphea ignea* A. DC.	Lythraceae
45	*Cupressus lusitanica* Mill.	Cupressaceae
46	*Cupressus macrocarpa* Hartw.	Cupressaceae
47	*Cuscuta campestris* Yunck.	Convolvulaceae
48	*Cymbopogon martini* (Roxb.) Wats.	Poaceae
49	*Dahlia pinnata* Cav.	Asteraceae
50	*Datura stramonium* L.	Solanaceae
51	*Delonix regia* (Boj.ex Hook.) Raf.	Fabaceae
52	*Dianthus chinensis* L.	Caryophyllaceae
53	*Dodonaea angustifolia* L. f.	Sapindaceae
54	*Dovyalis caffra* Hook.f. & Harv.	Salicaceae
55	*Duranta erecta* L.	Verbanaceae

56	*Echeveria secunda* Booth ex Lindl. .	Crassulaceae
57	*Erythrina abyssinica* Lam. ex DC.	Fabaceae
58	*Euphorbia milii* Des Moul. *;*	Euphorbiaceae
59	*Euphorbia tithymaloides* L.	Euphorbiaceae
60	*Falcataria moluccana* (L.) Greuter & R.Rankin	Fabaceae
61	*Ficus benjamina* L.	Moraceae
62	*Ficus elastic* Roxb. ex Hornem.	Moraceae
63	*Ficus microcarpa* L.F.	Moraceae
64	*Fuchsia magellanica* Lam.	Onagraceae
65	*Galinsoga parviflora* Cav.	Asteraceae
66	*Garcinia subelliptica* Merr.	Guttiferae
67	*Gazania rigens* (L.) Gaertn.	Asteraceae
68	*Gladiolus gandavensis* Van Houtte	Iridaceae
69	*Glandularia tenera (*Spreng.) Cabrera	Verbenaceae
70	*Glandularia x hybrida* (Groenland & Rümpler) G.L.Nesom & Pruski	Verbenaceae
71	*Grevillea robusta* R. Br	Proteaceae
72	*Hagenia abyssinica* (Bruce) J.F.Gmelin	Rosaceae
73	*Helianthus annuus* L.	Asteraceae
74	*Hibiscus rosa-sinensis* L.	Malvaceae
75	*Hippeastrum striatum*(Lam.)	amaryllidaceae
76	*Hydrangngea macrophylla* (H)|hortensia	Hydrangeaceae
77	*Impatiens hawkeri* (W. Bull)	Balsaminaceae
78	*Ipomoea purpurea* (L.) Roth	Convolvulaceae
79	*Iresine diffusefa*.f..herbstii	amaranthaceae
80	*Iris germanica* L.	Iridaceae
81	*Jacaranda mimosifolia* D. Don	Bignoniaceae
82	*Juniperus procera* Hochst.	Cupressaceae
83	*Lantana camara* L.	Verbenaceae
84	*Lavandula dentatata* L.	Lamiaceae

85	*Leucaena leucocephala* Lam.	Fabaceae
86	*Ligustrum ovalifolium* Hassk.	Oleaceae
87	*Lippia adoensis* Hochst. ex Walp.	Verbenaceae
88	*Malus sylvestris* Miller.	Rosaceae
89	*Mandevilla sanderi* Hemsl.	Apocynaceae
90	*Mangifera indica* L.	Anacardiaceae
91	*Melia azedarach* L.	Meliacea
92	*Mentha spicata* L.	Lamiaceae
93	*Millettia ferruginea* (Hochst.) Bak.	Fabaceae
94	*Mimosa pigra* L	Fabaceae
95	*Mirabilis jalapa* L.	Nyctaginaceae
96	*Nerium oleander* L	Apocynaceae
97	*Nicotiana glauca* Graham	Solanaceae
98	*Ocimum americanum* L.	Lamiaceae
99	*Ocimum lamiifolium* Hochst. ex. Benth.	Lamiaceae
100	*Olea europaea* L. subsp. cuspidata	Oleaceae
101	*Osteospermum ecklonis* (DC.) Norl.	Asteraceae
102	*Oxytenanthera abyssinica* (A. Rich.) Munro.	Poaceae
103	*Parkinsonia aculeata* L.	Fabaceae
104	*Parthenium hysterophorus* L.	Asteraceae
105	*Pelargonium hortorum* LH Bailey-	Geraniaceae
106	*Persea americana* Mill.	Lauraceae
107	*Phoenix canariensis* H.Wildpret	Arecaceae
108	*Phyllanthus urinaria* L.	phyllanthaceae
109	*Pilea pepermioides* Diels.	Urticaeceae
110	*Pinus patula* Schiede ex Schltdl. & Cham.	Pinaceae
111	*Plumeria rubra* L.	Apocynaceae
112	*Podocarpus falcatus* (Thunb.) Mirb.	Podocarpaceae
113	*Poikilospermum suaveolens* (Blume) Merr.	Urticaeceae

114	*Prunus africana* (Hook.f.) Kalkm.	Rosaceae
115	*Psidium guajava* L.	Myrtaceae
116	*Pterolobium stellatum* (Forssk.) Brenan	Fabaceae
117	*Pyrostegia venusta* (Ker Gawl.) Miers	Bignoniaceae
118	*Rhodiola pachyclados* (Aitch. & Hemsl.) H.Ohba	Crassulaceae
119	*Ricinus communis* L.	Euphorbiaceae
120	*Rosa x-richardii* Rehder.	Rosaceae
121	*Rosmarinus officinalis* L.	Lamiaceae
122	*Ruta chalepensis* L.	Rutaceae
123	*Saccharum officinarum* L.	Poaceae
124	*Salix purpurea* L.	Salicaceae
125	*Salvia coccinea Buc'hoz ex Etl.*	Lamiaceae
126	*Salvia farinacea* Benth.	Lamiaceae
127	*Salvia leucantha* Cav.	Lamiaceae
128	*Salvia officinalis* L.	Lamiaceae
129	*Salvia splendens* Sellow ex Nees	Lamiaceae
130	*Salvia tiliifolia* Vahl.	Lamiaceae
131	*Sanguisorba officinalis* L.	Rosaceae
132	*Sansevieria trifasciata* hort. ex Prain	Asparagaceae
133	*Sedum dendroideum* Moc. & Sessé ex DC.	Crassulaceae
134	*Senna didymobotrya (*Fresen.) Irwin & Barneby	Fabaceae
135	*Sesbania sesban*(L.)	Fabaceae
136	*Spathodea campanulata* P. Beauv.	Bignoniaceae
137	*Stephania abyssinica* (Dillon & A. Rich.) Walp.	Menispermaceae
138	*Symphyotrichum* novi-belgii	Asteraceae
139	*Syngonium podophyllum* Schott	Araceae
140	*Terminalia catappa* L.	Combretaceae
141	*Thymus schimperi* L.	Lamiaceae
142	*Thymus vularis* L.	Lamiaceae

143	*Tulbaghia violacea* Harv.	amaryllidaceae
144	*Verbesina encelioides* (Cav.) Benth. & Hook. f.	Asteraceae
145	*Vernonia amygdalina* Del.	Asteraceae
146	*Vigna radiate* (L.) R. Wilczek)	Fabaceae
147	*Vinca major* L.	Apocynaceae
148	*Yucca gigantean* Lem.	Asparagaceae
149	*Zantedeschia aethiopica*(L.)	Araceae