Conservation of wild nutmeg (*Myristica* spp) in Halmahera based on morphological markers

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A**bstract.** The population of wild nutmeg (*Myristica spp*) in Halmahera, North Maluku, represents an important genetic resource requiring conservation to preserve the germplasm of this economically valuable spice plant. Limited morphological data may hinder its optimal utilization. This study identifies morphological diversity as the basis for conserving wild nutmeg accessions growing naturally in Halmahera forests, using 20 morphological markers measured on fruit, seed, leaf, and mace characters. Descriptive analysis, ANOVA, and cluster analysis revealed significant phenotypic variation. The Wayamli accession has larger fruit and leaf sizes, while the Patani accession shows distinctive seed shapes and thinner mace. These findings confirm ecological differentiation and highlight the importance of morphological markers in germplasm conservation. Furthermore, conservation strategies are linked to climate change mitigation and adaptation, positioning wild nutmeg as a biodiversity resource that supports carbon sequestration, ecosystem resilience, and sustainable agroforestry development.

1 Introduction

Nutmeg (*Myristica spp.*) is an indigenous Indonesian spice plant with significant economic, social, and pharmacological value Since the colonial era, nutmeg has been a flagship commodity linking the archipelago to international trade through its essential oils and bioactive compounds [1]. In the contemporary era, however, its strategic role is defined not only by its health and industrial benefits but also by its resilience in the face of climate change pressures. Nutmeg also holds potential as part of climate adaptation solutions, which agroforestry systems, can enhance ecosystem resilience, maintain soil moisture, and sequester carbon [2].

Wild nutmeg species grow naturally in the tropical forests of Halmahera and Bacan Islands [3]. These wild populations function as genetic reservoirs, storing superior traits such as resistance to environmental stress, ecological adaptation, and stable productivity potential. Establishing in situ conservation areas in Halmahera to preserve wild nutmeg forest cover, contribution to enhances carbon sequestration and reduces emissions from deforestation [4]. Rehabilitatin critical and post-mining lands to increase carbon absorption

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capacity and reduce risks of flooding and erosion. The existence of wild nutmeg germplasm is an important asset for future development of superior varieties [5]. Information on population structure, distribution patterns, and genetic diversity of wild nutmeg remains very limited. Previous studies have focused more on cultivated nutmeg, while conservation and characterization of wild nutmeg have received infficient attention. This knowledge gap may hinder the optimal utilization of wild nutmeg genetic resources [2,3].

Morphological characterization is a rapid, simple, and effective approach to detect phenotypic diversity in plants [6]. Through morphological observations, researchers can identify differences and similarities among accessions, providing g an initial overview of existing genetic diversity. This method is also relevant to support germplasm conservation and plant breeding programs. Morphological characterization plays a role in determining important agronomic traits, taxonomic classification, and estimating genetic relationships among populations. Morphological data are useful for conservation and serve as the basis for developing superior varieties suited to local and global needs. Utilizing morphological diversity (large fruits, elongated seeds, broad leaves) for breeding varieties tolerant to fluctuations in temperature and rainfall, contribute to supports agricultural adaptation to climate change [3,7]

The lack of information on wild nutmeg in Halmahera requires systematic research to document morphological diversity. This effort is crucial to ensure sustainable conservation and utilization of wild nutmeg germplasm, avoiding genetic erosion and loss of valuable genetic resources due to deforestation and land conversion. Engaging Halmahera communities in sustainable conservation practices aligned with traditional ecological knowledge. Involving Halmahera communities in sustainable conservation and utilization of wild nutmeg to reduces local climate risks through environmentally friendly traditional practices. This study aims to identify morphological diversity of wild nutmeg in Halmahera as the basis for germplasm conservation. The results are expected to provide strategic information for genetic resource management, support breeding programs, strengthen Indonesia's position in preserving global spice biodiversity, and provides scientific data for biodiversity-based mitigation and adaptation policies.

2 Materials and Methods

This research was conducted in the forest areas of Halmahera Island, North Maluku Province, covering Central Halmahera and East Halmahera Regencies. The study sites were chosen because they represent natural habitats of wild nutmeg (Myristica spp), which remain relatively preserved despite facing threats of deforestation and land conversion. Three observation blocks were established: Wayamli, Maba-Bicoli, and Patani, each with different topographic and geological conditions. Geographically, Central Halmahera lies between 0°45' N – 0°15' S and 127°45' – 129°26' E, with an area of 8,381.48 km². East Halmahera is located between 1°4' – 0°40' S and 126°45' – 130°30' E. These geographical conditions provide significant ecological variation, enabling morphological diversity among wild nutmeg across observation blocks.

The research material consisted of wild nutmeg trees growing naturally in Halmahera forests. Observed accessions were mature trees, while seedlings and saplings were excluded due to sampling limitations. Sampling used the plotless sampling technique, involving direct observation of individual trees without establishing sample plots [8]. This technique was chosen to suit heterogeneous and difficult-to-access forest conditions. Through this method, 64 wild nutmeg accessions were identified across the three observation blocks. Morphological characterization was conducted by observing 20 plant traits, including fruit (length, width, index, shape, color, flesh thickness), mace (color, taste, thickness), seed (shell

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color, length, width, index, shape, aroma, weight per seed), and leaf (length, width, index). Traits were observed qualitatively and quantitatively according to standard descriptors.

Table 1. Guidelines for Measuring Morphological Traits of Wild Nutmeg

Morphological Trait	Score/Measurement	Description
Leaf Length	Quantitative	Measurement in centimeters
Leaf Width	Quantitative	Measurement in centimeters
Leaf Size (Index)	Leaf Index	Leaf length divided by leaf width
Fruit Length	Quantitative	Measurement in centimeters
Fruit Width	Quantitative	Measurement in centimeters
Fruit Index	Fruit Index	Fruit length divided by fruit width 1 = ID < 1.0; 2 = ID 1.0–1.15; 3 = ID 1.16–1.25; 4 = ID 1.26–1.51; 5 = ≥ 1.51
Fruit Shape	Oblate (1), Round (2), Oval (3), Slightly Elliptical (4), Elliptical (5)	Scoring categories
Ripe Fruit Color	1, 2, 3, 4	1 = Yellow; 2 = Yellowish Green; 3 = Yellowish Brown; 4 = Yellowish Red
Fruit Flesh Color	1, 2	1 = White; 2 = Whitish Brown
Fruit Flesh Thickness	Quantitative	Thickest flesh divided by thinnest flesh
Mace Color	1, 2, 3	1 = Pink; 2 = Blood Red; 3 = Ivory White
Mace Taste	1, 2	1 = Mild; 2 = Spicy
Mace Thickness	1, 2	1 = Thin; 2 = Thick
Seed Shell Color	1, 2, 3	1 = Brown; 2 = Dark Brown; 3 = Shiny Black
Seed Length	Quantitative	Measurement in centimeters
Seed Width	Quantitative	Measurement in centimeters
Seed Index	Seed Index	Seed length divided by seed width 1 = ID < 1.0; 2 = ID 1.0–1.15; 3 = ID 1.16–1.25; 4 = ID 1.26–1.51; 5 = ≥ 1.51
Seed Shape	Oblate (1), Round (2), Oval (3), Slightly Elliptical (4), Elliptical (5)	Scoring categories
Seed Aroma	1, 2	1 = Moderate Aroma; 2 = Strong Aroma
Seed Weight per Unit	Quantitative	Measurement in grams

Quantitative data were analyzed using descriptive statistics, including mean, median, standard deviation, and coefficient of variation. ANOVA was used to test differences among observation blocks, while cluster analysis grouped accessions based on morphological similarities. This approach provided an overview of both diversity and uniformity among populations. Accessions were named based on the village or observation site where the trees were found, to facilitate identification and field tracking. Thus, morphological data obtained serve not only as scientific information but also as the basis for sustainable management of wild nutmeg germplasm.

3 Results and Discussion

This study successfully identified 64 wild nutmeg (*Myristica spp*) accessions from three observation blocks in East Halmahera, namely Wayamli, Maba-Bicoli, and Patani, located in Central Halmahera. The observed accessions were mature trees, allowing optimal measurement of morphological traits. The distribution of accessions varied among blocks: 17 accessions in Wayamli, 22 in Maba-Bicoli, and 25 in Patani. These differences reflect the ecological conditions of each block, including topography, geology, and the degree of anthropogenic disturbance [9][10].

Fruit traits showed significant variation. Wild nutmeg fruits in Wayamli had an average length of 5.8 cm and width of 5.2 cm, larger than those in Maba-Bicoli (4.8 cm × 4.4 cm) and Patani (5.2 cm × 4.9 cm). This indicates phenotypic differences influenced by environmental conditions. The fruit index was relatively uniform across blocks, with an average value of 1.08. This uniformity suggests that although fruit size differs, the proportion of length to width remains consistent, serving as an indicator of morphological stability [11]

The color of ripe fruits varied among blocks. Wayamli was dominated by yellowish-brown fruits, Maba-Bicoli by yellow fruits, and Patani by yellowish-green fruits. This variation can serve as a morphological marker distinguishing accessions across locations. The fruit flesh of wild nutmeg in all blocks was generally white, with average thicknesses of 2.1 cm in Wayamli, 2.0 cm in Maba-Bicoli, and 1.9 cm in Patani. Differences in flesh thickness have implications for essential oil production potential.

Mace (aril) showed variation in thickness and taste. Wayamli accessions had thicker mace with moderate taste, while Maba-Bicoli and Patani accessions had thinner mace with a spicy taste. This trait is important since mace is a high-value commodity. Seeds of wild nutmeg also showed diversity in shape and size. Wayamli seeds were longer (3.1 cm) and heavier (15 g/seed) compared to Maba-Bicoli (2.5 cm; 12 g/seed) and Patani (2.2 cm; 10 g/seed). These differences indicate genetic differentiation. Seed shell color was generally dark brown across all blocks, making this trait relatively uniform. However, seed shape varied from round to elongated, with Patani accessions more frequently producing elongated seeds. Leaf traits also showed variation. Wayamli accessions had longer (16.4 cm) and wider (6.9 cm) leaves compared to Maba-Bicoli (11.6 cm × 5.1 cm) and Patani (11.7 cm × 5.1 cm). This reflects adaptation to different ecological conditions.

Table 2. Tukey Test of Morphological Traits of Wild Nutmeg (*Myristica spp*) Accessions

Morphological Traits	Accessions	Tukey HSD 0.05		Mean Difference (I-J)	Std. Error	Sig.
Fruit Length	Wayamli	5.82	a	1.00535*	.19735	.000
	Maba-Bicoli	4.82	b	.54353*	.19212	.017
	Patani	5.28	c	-1.00535*	.19735	.000
Fruit Width	Wayamli	5.24	a	.96845*	.20979	.000
	Maba-Bicoli	4.27	b	.12118	.20423	.824
	Patani	5.12	b	-.96845*	.20979	.000
Fruit Index	Wayamli	1.12	a	.03810	.03398	.505
	Maba-Bicoli	1.08	a	.05685	.03308	.207
	Patani	1.06	a	-.03810	.03398	.505
Fruit Shape	Wayamli	2.47	a	.334	.295	.498
	Maba-Bicoli	2.14	a	-.089	.287	.948
	Patani	2.56	a	-.334	.295	.498
Ripe Fruit Color	Wayamli	2.88	a	1.337*	.284	.000
	Maba-Bicoli	1.55	a	1.282*	.277	.000
	Patani	1.60	b	-1.337*	.284	.000
Fruit Flesh Thickness	Wayamli	1.22	a	.00647	.04498	.989
	Maba-Bicoli	1.21	a	-.06713	.04379	.283
	Patani	1.28	a	-.00647	.04498	.989
Mace Color	Wayamli	1.94	a	.259	.136	.144
	Maba-Bicoli	1.68	a	.221	.132	.223
	Patani	1.72	a	-.259	.136	.144
Mace Thickness	Wayamli	1.94	a	.668*	.140	.000
	Maba-Bicoli	1.27	a	.461*	.137	.004
	Patani	1.48	b	-.668*	.140	.000
Seed Shell Color	Wayamli	1.88	a	.564*	.163	.003
	Maba-Bicoli	1.32	b	-.078	.158	.876
	Patani	1.96	b	-.564*	.163	.003
Seed Length	Wayamli	2.88	a	.33690*	.13750	.045
	Maba-Bicoli	2.55	b	.80235*	.13385	.000
	Patani	2.08	c	-.33690*	.13750	.045
Seed Width	Wayamli	2.20	a	.19567	.08396	.059
	Maba-Bicoli	2.00	b	.74415*	.08174	.000
	Patani	1.45	c	-.19567	.08396	.059
Seed Index	Wayamli	1.29	a	-.04506	.04524	.582
	Maba-Bicoli	1.34	a	-.30293*	.04404	.000
	Patani	1.59	b	.04506	.04524	.582
Seed Shape	Wayamli	4.53	a	.757	.341	.076
	Maba-Bicoli	3.77	a	.609	.332	.166
	Patani	3.92	a	-.757	.341	.076
Seed Weight per Unit	Wayamli	5.51	a	-.63048	.27109	.060
	Maba-Bicoli	6.14	b	.24908	.26391	.615
	Patani	5.26	a	.63048	.27109	.060
Leaf Length	Wayamli	16.40	a	4.76364*	.93441	.000
	Maba-Bicoli	11.64	b	3.92000*	.90964	.000
	Patani	12.48	b	-4.76364*	.93441	.000
Leaf Width	Wayamli	6.91	a	1.86631*	.43429	.000
	Maba-Bicoli	5.05	b	1.55176*	.42278	.001
	Patani	5.36	b	-1.86631*	.43429	.000
Leaf Size (Index)	Wayamli	2.43	a	.12549	.11326	.513
	Maba-Bicoli	2.31	a	.07883	.11026	.756

	Patani	2.35	a	-.12549	.11326	.513

Standard deviation analysis showed that leaf length in Wayamli had the highest variability (δ = 4.8), while fruit flesh color across all blocks was relatively uniform (δ = 0.0–0.2). This confirms that some traits are more stable than others. Uniformity in fruit and seed indices indicates morphological stability, while variation in leaf and seed length demonstrates genetic diversity that can be utilized in breeding.

Table 3. Description of Morphological Traits of Wild Nutmeg in Natural Habitats of Halmahera Forests (Wayamli, Maba-Bicoli, and Patani Blocks)

Character	Description of Wild Nutmeg Morphological Character		
	Wayamli Accessions	**Maba-Bicoli Accessions**	**Patani Accession**
1. Fruit			
a. Fruit Length	Xt = 5,8 (me=5.8; δ=0,5)	Xt = 4,8 (me=4.6; δ=0,5)	Xt = 5.19 (me=5.12; δ=0,54)
b. Fruit Width	Xt = 5.2 (me=5.4; δ=0,6)	Xt = 4,4 (me=4,4; δ=0,5)	Xt = 4,94 (me=4,80; δ=0,45)
c. Fruit Index	Xt = 1.12 (me=1.11;δ=0,12)	Xt = 1,08 (me=1,05;δ=0,11)	Xt = 1.05 (me=1.09;δ=0,11)
d. Fruit Shape	Round	Bulat	Oval
e. Fruit color	Whitish Brown	Whitish Brown	Yellowish Green
2. Fruit Flesh			
a. Fruit Flesh Color	White	White	Putih
b. Fruit Flesh Thickness	Xt = 2.10 (me=2,17; δ=0,87)	Xt = 2.09 (me=1,87; δ=0,86)	Xt = 1,90 (me=1,64; δ=0,85)
3. Mace			
a. Mace Color	Blood Red	Blood Red	Blood Red
b. Mace Teste	Mild	Spicy	Mild
c. Mace Thickness	Thick	Thin	Thin
4. Seed			
a. Seed Shell color	Dark Brown	Brown	Dark Brown
b. Seed Length	Xt = 3,0 (me=3,1; δ=0,4)	Xt = 2.6 (me=2,5; δ=0,3)	Xt = 2,26 (me=2.24; δ=0,27)
c. Seed Width	Xt = 2.2 (me=2,4; δ=0,6)	Xt = 2.0 (me=2,0; δ=0,2)	Xt = 1.45 (me=1.41; δ=0,19)
d. Seed Index	Xt = 1.44 (me=1,31; δ=0,40)	Xt = 1,34 (me=1,34; δ=0,08)	Xt = 1.58 (me=1,56; δ=0,23)
e. Seed Shape	Elliptical	Slightly Elliptica	Slightly Elliptica
f. Seed Aroma	Moderate Aroma	Moderate aroma	Moderate aroma
g. Seed Weigth	Xt = 13.9 (me=15; δ=4,2)	12.1 (me=12; δ=2.8)	Xt = 12.86 (me=10; δ=4,6)
5. Leaf			
a. Leaf Length	Xt = 16.4 (me=15.1; δ=24.8)	Xt = 11.6 (me=11,0; δ=1.7)	Xt = 11,74 (me=11,55; δ=1,6)
b. Leaf Width	Xt = 6.9 (me=7.3; δ=2.0)	Xt = 5.1 (me=5,0; δ=1,0)	Xt = 5.11 (me=5.2; δ=0,62)
c. Leaf Index	Xt = 2,43 (me=2,42; δ=0,39)	Xt = 2.31 (me=2,25; δ=0,35)	Xt = 2,31 (me=2,3; δ=0,3)

Note: Xt = Mean; me = Median; δ = Standard Deviation

Cluster analysis grouped accessions based on morphological similarities. Wayamli accessions tended to form a separate cluster due to larger fruit and leaf sizes, while Maba-Bicoli and Patani accessions were more closely related, characterized by thinner mace and smaller seeds. These findings emphasize ecological differentiation shaped by geological and topographic conditions. The morphological diversity observed indicates ecological differentiation among observation blocks. Geological, topographic, and soil factors play roles in shaping phenotypic variation of wild nutmeg in Halmahera [12][2].

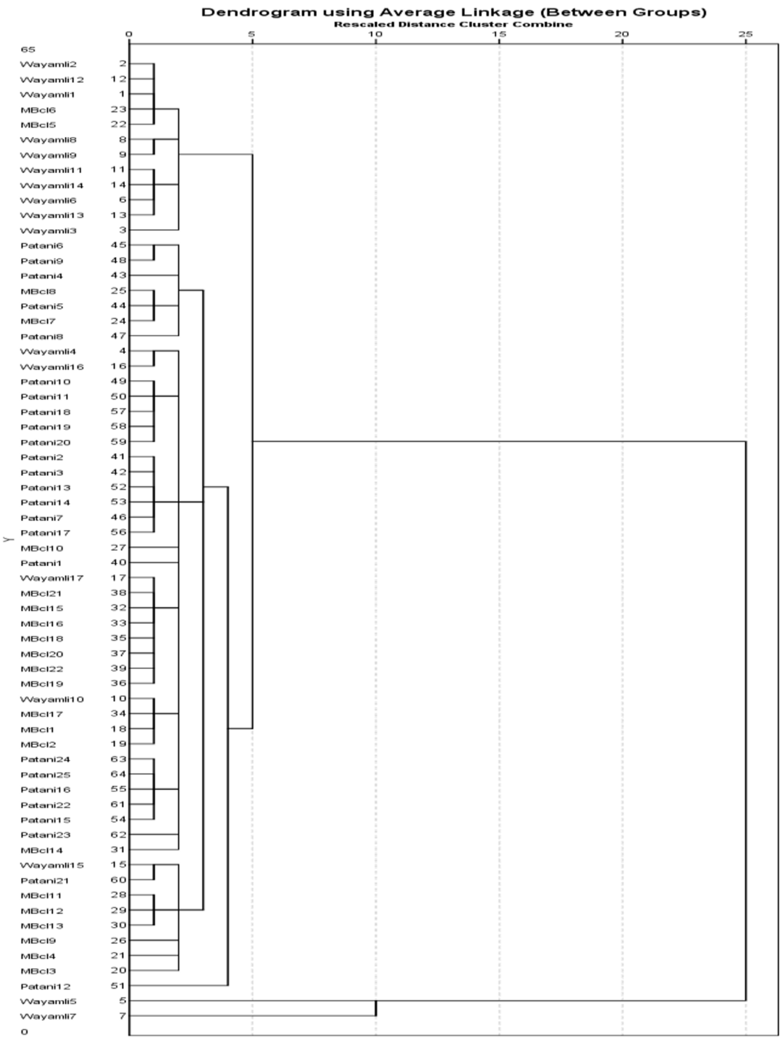

Fig. 1. Dendrogram of Morphological Traits of Wild Nutmeg Accessions in Wayamli, Maba-Bicoli, and Patani

The findings emphasize the importance of morphological markers in conserving wild nutmeg germplasm. Morphological data can be used to identify superior accessions, support breeding programs [13], and serve as the basis for conservation policies and management of Indonesia's spice biodiversity [14]. In situ conservation of wild nutmeg in East and Central Halmahera can be achieved through protection of natural habitats from deforestation caused by mining and shifting cultivation practices. The dual role of wild nutmeg conservation preserving Indonesia's spice biodiversity while simultaneously contributing to climate resilience, mitigating of climate change, and sustainable development [2][15].

Table 2. Insitu Conservation Points of Wild Nutmeg (Myristica spp) in Halmahera Forests, North Maluku

Point	Location	Geographic Coordinates		Physical Condition of the Land		
		East Longitude (BT)	North Latitude (LU)	Elevasi	Topography	Geologists
1	Wayamli	128° 30' 33.001" E	1° 0' 41.000" N	104	A bit steep (30-45%)	Tufaan Sandstone
2	Wayamli	128° 30' 34.999" E	1° 0' 42.998" N	129	A bit steep (30-45%)	Tufaan Sandstone
3	Wayamli	128° 30' 10.001" E	1° 0' 10.001" N	101	A bit steep (30-45%)	Tufaan Sandstone
4	Wayamli	128° 30' 33.001" E	1° 0' 49.000" N	133	A bit steep (30-45%)	Tufaan Sandstone
5	Wayamli	128° 30' 36.000" E	1° 0' 36.000" N	116	A bit steep (30-45%)	Tufaan Sandstone
6	Wayamli	128° 29' 33.000" E	0° 59' 0.000" N	16	Flat (0-3%)	Aluvium
7	Wayamli	128° 29' 3.998" E	0° 59' 53.999" N	56	A bit steep (30-45%)	Tufaan Sandstone
8	Wayamli	128° 28' 52.000" E	0° 59' 49.999" N	38	A bit steep (30-45%)	Tufaan Sandstone
9	Wayamli	128° 28' 45.001" E	0° 59' 55.000" N	88	A bit steep (30-45%)	Tufaan Sandstone
10	Wayamli	128° 28' 34.197" E	1° 0' 0.770" N	149	A bit steep (30-45%)	Tufaan Sandstone
11	Maba-Bicoli	128° 33' 6.001" E	0° 33' 24.998" N	85	A bit steep (30-45%)	Limestone
12	Maba-Bicoli	128° 33' 4.471" E	0° 32' 57.579" N	91	Corrugated (8-15%)	Limestone
13	Maba-Bicoli	128° 31' 16.000" E	0° 33' 25.999" N	107	Hilly (15-30%)	Limestone
14	Maba-Bicoli	128° 31' 13.001" E	0° 33' 58.000" N	67	Hilly (15-30%)	Limestone
15	Maba-Bicoli	128° 30' 58.000" E	0° 34' 5.999" N	55	Hilly (15-30%)	Limestone
16	Patani	128° 44' 51.618" E	0° 17' 52.718" N	272	A bit steep (30-45%)	Tufaan Sandstone
17	Patani	128° 44' 52.755" E	0° 17' 55.414" N	284	Steep (>45%)	Tufaan Sandstone
18	Patani	128° 44' 52.793" E	0° 17' 56.891" N	291	Steep (>45%)	Tufaan Sandstone
19	Patani	128° 44' 48.391" E	0° 17' 57.271" N	284	Steep (>45%)	Tufaan Sandstone
20	Patani	128° 48' 53.009" E	0° 16' 39.397" N	220	A bit steep (30-45%)	Tufaan Sandstone
21	Patani	128° 48' 51.868" E	0° 16' 41.083" N	237	A bit steep (30-45%)	Tufaan Sandstone
22	Patani	128° 48' 49.222" E	0° 16' 42.434" N	241	A bit steep (30-45%)	Tufaan Sandstone
23	Patani	128° 48' 47.346" E	0° 16' 40.745" N	231	A bit steep (30-45%)	Tufaan Sandstone
24	Patani	128° 48' 40.831" E	0° 16' 31.627" N	136	A bit steep (30-45%)	Tufaan Sandstone
25	Patani	128° 48' 39.192" E	0° 16' 30.111" N	143	A bit steep (30-45%)	Serpentinit
26	Patani	128° 48' 35.380" E	0° 16' 24.374" N	92	A bit steep	Serpentinit
27	Patani	128° 48' 31.211" E	0° 16' 19.708" N	69	A bit steep	Serpentinit
28	Patani	128° 48' 29.816" E	0° 16' 13.214" N	19	A bit steep (30-45%)	Serpentinit
29	Patani	128° 48' 28.564" E	0° 16' 10.760" N	5	Flat (0-3%)	Aluvium

The insitu conservation of wild nutmeg in Halmahera forests is distributed across three main areas: Wayamli, Maba-Bicoli, and Patani. Each conservation point is characterized by distinct geographic coordinates, elevation, topography, and geological formations. Wayamli Area Conservation points in Wayamli are located between 128°28′–128°30′ East Longitude and 0°59′–1°00′ North Latitude, with elevations ranging from 16 to 149 meters above sea level. Most sites exhibit moderately steep slopes (30–45%), underlain by Tufaan Sandstone, A few points, such as Point 6 (16 m) and Point 29 (5 m), are situated on flat terrain (0–3%), formed by alluvial deposits, and variation in slope and geology provides diverse microhabitats for nutmeg populations.

Maba-Bicoli Area Located further south, the Maba-Bicoli sites lie between 128°30′–128°33′ East Longitude and 0°32′–0°34′ North Latitude, with elevations ranging from 55 to 107 meters. The terrain here is dominated by limestone formations, with corrugated (8–15%)

and hilly slopes (15–30%), and these limestone landscapes create unique ecological niches, supporting nutmeg growth in rugged terrain.

Patani Area The Patani conservation points extend across 128°44′–128°48′ East Longitude and 0°16′–0°17′ North Latitude, with elevations ranging from 5 to 291 meters. The majority of sites are moderately steep (30–45%) or steep (>45%), particularly at higher elevations (Points 16–19, 272–291 m), geological substrates vary, including Tufaan Sandstone, Serpentinite, and alluvial deposits, and the diversity of rock types and slope conditions in Patani highlights its importance as a conservation zone, offering both highland and lowland habitats for nutmeg species.

The conservation points demonstrate a wide range of elevations (5–291 m), topographies (flat, corrugated, hilly, moderately steep, and steep), and geological substrates (sandstone, limestone, serpentinite, and alluvium). This diversity reflects the ecological adaptability of wild nutmeg and underscores the importance of Halmahera's varied landscapes for long-term in situ conservation.

4 Conclusion

This study successfully identified 64 wild nutmeg (Myristica spp) accessions in Halmahera, North Maluku, through morphological characterization across three observation blocks: Wayamli, Maba-Bicoli, and Patani. Significant phenotypic diversity was observed, particularly in fruit, seed, leaf, and mace traits. Wayamli accessions exhibited larger fruits and leaves, Maba-Bicoli accessions showed oval-shaped fruits with thin mace, while Patani accessions were characterized by elongated seeds and thinner mace. Uniformity in fruit and seed indices indicates morphological stability, whereas variation in leaf and seed length confirms genetic differentiation among populations. The morphological diversity reflects ecological adaptation to different geological and topographic conditions in each observation block. Morphological markers proved effective as a basis for conserving wild nutmeg germplasm, supporting the breeding of superior varieties, sustainable germplasm management, and the preservation of Indonesia's spice biodiversity.

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