Journal of Tropical Biodiversity and Biotechnology
Volume 11, Issue 02 (2026): jtbb15610
DOI: 10.22146/jtbb.15610

Research Article

Aspect-Driven Variations in Soil and Flora: Insights from Menoreh Highland

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Keywords:
Floral biodiversity
Humid area
Nutrient dynamics
Slope aspect
Tropical region
Submitted:
08 August 2024
Accepted:
16 November 2025
Published:
20 April 2026
Editors:
Furzani Binti Pa'ee
Sri Nopitasari

ABSTRACT

This study examined the influence of slope aspects on soil chemical properties and floral biodiversity within the Menoreh Highland in Indonesia, with a specific focus on the east, north, south, and west-facing slopes. The sampling protocol involved collecting, identifying, and subsequently calculating biodiversity metrics, including Shannon-Wiener, Simpson Index, Richness, and Evenness for each slope aspect. The soil variables scrutinised encompassed moisture content, pH, soil organic matter (SOM), soil organic carbon (SOC), total nitrogen, carbon-to-nitrogen (C/N) ratio, and cation exchange capacity (CEC). Statistical analyses, including ANOVA followed by LSD ($\alpha = 5$ %), were employed, and correlations between soil chemical properties, microclimate parameters, and biodiversity indices were computed. Humid slopes (south and west) exhibited diminished solar radiation, air temperature, pH, total phosphorus (P), total potassium (K), available calcium (Ca), available magnesium (Mg), coupled with elevated humidity, soil moisture content, SOM, SOC, total nitrogen, CEC, and available sulphur (S) in comparison to arid slopes (east and north). Variations due to varied microclimates and soil chemical properties cause differences in floral diversity. The east slope emerged as the pinnacle of diversity, as delineated by indices such as Shannon-Wiener and Simpson Index, Evenness, and Richness, characterised predominantly by the prevalence of shrub species. Conversely, the west slope exhibited the lowest diversity and was principally dominated by arboreal species. This comprehensive exploration underscores the intricate interplay between slope aspect, soil properties, microclimate, and floral diversity, elucidating the intricate ecological dynamics in the Menoreh Highland.

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How to cite:
Avianto, Y. et al., 2026. Aspect-Driven Variations in Soil and Flora: Insights from Menoreh Highland. *Journal of Tropical Biodiversity and Biotechnology*, 11(2), jtbb15610. doi: 10.22146/jtbb.15610

INTRODUCTION

Menoreh Highland, located in Kulon Progo, Yogyakarta, Indonesia, is a mountainous region characterised by steep slopes and a diverse range of vegetation types (Sholikah et al. 2021). The slope aspect, or the direction a slope faces in a mountain, is known to be a critical factor affecting soil chemical properties, which in turn impact crop productivity, ecosystem functioning, and soil conservation (Wu et al. 2024). Differences in solar insolation may occur in a mountain according to the slope aspect of the site, thereby forming a range of microclimates in multifaceted landscapes (Pandita et al. 2019). Consequently, microclimate is often linked to soil moisture and the distribution of particular plant communities. However, the influence of slope aspects on soil chemical properties in Menoreh Highland remains largely understudied.

Numerous studies have investigated the effect of slope aspect on soil chemical properties in various regions worldwide, including Indonesia. However, few studies have focused on Menoreh Highland, despite its ecological and agricultural significance. Previous research suggests that slope aspects can influence soil chemical properties by affecting soil temperature, moisture, organic matter content, and nutrient availability (Fan et al. 2020). For instance, west-facing slopes are generally cooler and moister because they receive less insolation, which can affect nutrient availability and microbial activity. In contrast, east-facing slopes may receive more insolation and be warmer, which can alter soil nutrient cycling and plant growth (Enescu et al. 2022). The study in the Qilian Mountains reveals a significant influence of slope aspect on soil organic carbon (SOC). Three slope aspects—south-facing, semi-sunny, and semi-shady—exhibit distinct variations in SOC, soil properties, and vegetation. The semi-shady slope stands out with significantly higher SOC, vegetation cover, and biomass, approximately twice that of the south-facing slope. Plant community composition varies by slope aspect (Qin et al. 2016). A specific study by Bangroo et al. (2017), found higher content for both SOC and N under the south-facing aspect compared to the north-facing aspect, and this trend persisted with increasing soil depth in the Himalayan Mawer Forest Range. Another study in the Zhifanggou watershed of Ansai, Shaanxi Province, shows that slope aspect influences six different nitrogen forms, including nitrate-N, organic N, mineralizable N, microbial biomass nitrogen (MBN), soluble organic nitrogen (SON), and ammonium-N. Notably, the shady and half-shady slopes exhibited significantly greater levels of five nitrogen forms (excluding SON) (Huang et al. 2015)

The slope aspects can have a significant effect on the biodiversity and distribution of plant communities, particularly in relation to the amount of insolation received (Singh 2018; Yang et al. 2020). The slopes that tend to receive less insolation are therefore cooler and moister. This circumstance can create conditions that are more favourable for shade-tolerant plant species, such as ferns and mosses, while making it more difficult for sun-loving species to thrive (Dearborn & Danby 2017; Pelletier et al. 2018). The slope aspects significantly influence plant diversity in the dry valley of the upper reaches of the Min River in the Hengduan Mountains Region, southwestern China. The findings revealed notable differences between north-facing and south-facing slopes. Specifically, north-facing slopes exhibit increased biomass, height, and β diversity, along with decreased density and coverage. Interestingly, the wetter site exhibits an opposite trend in α diversity (Yang et al. 2020). Another study by Méndez-Toribio et al. (2016) in southern Mexico revealed distinct variations between south-facing (S) and north-facing (N) slopes: South-facing slopes exhibit higher individual sizes, abundance, and species diversity, with values increasing towards the upper portion of the slope, whereas north-facing slopes show a decline in these parameters with increasing elevation.

The north face of mountains in the Northern Hemisphere exhibits high species diversity due to its moist and shady conditions. Results show rich herbaceous diversity, with 65.8 % species varying among sites. Canonical correspondence analysis suggests that environmental variables play a role in species composition across different sub-slopes (Pandita et al. 2019). The study's objectives are to identify differences in soil chemical properties and floral biodiversity among various slope aspects and to determine the factors contributing to these differences. The study's outcomes provide essential information for sustainable land management and agriculture in Menoreh Highland, helping farmers make informed decisions about crop selection, nutrient management, and soil conservation practices.

MATERIALS AND METHODS

Research Site

The study was conducted from September 2020 to February 2022 in Kayugedhe and Sumbo hamlets of Gerbosari village, Samigaluh subdistrict, Kulon Progo district, Yogyakarta Special Region (lat. 7 ° 65' 26" S, long. 110 ° 17' 38" E), with an elevation ranging from 620 to 820 m asl. Based on its characteristics, the soil at the study site is classified as an inceptisol. The area is characterised by a humid tropical monsoon climate with an average annual rainfall of approximately 2,200 mm and a mean temperature of 26–28 °C. The soil at the study site is classified as an Inceptisol according to the USDA Soil Taxonomy. The Inceptisols in this area are characterised by the presence of a cambic horizon, which indicates moderate development due to physical alteration, chemical transformation, or material translocation.

Twelve study plots were established on four slope aspects (north, east, south, and west-facing slope with three replicate plots per aspect. Each plot measured 20 × 20 m and represented different hill positions: upper, middle, and lower slopes. The slope aspects were determined using a compass and verified with a digital elevation model (DEM) in ArcGIS 10.8 software with a 30-m spatial resolution. The north-facing slope was defined as 0°, while 90°, 180°, and 270° represented east-, south-, and west-facing slopes, respectively. The selected plots were located in areas without visible signs of recent disturbance, such as landslides, clearing, or cultivation (Figure 1 & Table 1).

Microclimate and Soil Properties Measurement

Microclimate measurements were conducted 2 m above the ground surface at the centre of each 20 × 20 m plot. Observations were made at three different time intervals per day (08:00, 12:00, and 16:00) for three consecutive clear days each month. Parameters measured included air temperature (°C), relative humidity (%), and light intensity (lux) using a portable thermo-hygrometer and digital light meter (Lutron LM-8102).

Soil samples were collected at a depth of 30 cm and placed in plastic containers. Soil moisture content was measured by weighing 10 g of an air-dried soil sample in a known-weight aluminium cup. The dish containing the soil was then dried in an oven at a constant temperature of 110 ± 1 °C until its weight became constant. After cooling, the resulting soil was weighed again. The equation for calculating soil moisture content is as follows:

$$SWC\ (\%) = \frac{(W2 - W3)}{(W3 - W1)} \times 100$$

W1 = empty cup weight
W2 = empty cup weight + soil field weight
W3 = empty cup weight + soil dry weight

Soil organic carbon was determined by dichromate oxidation, and it was

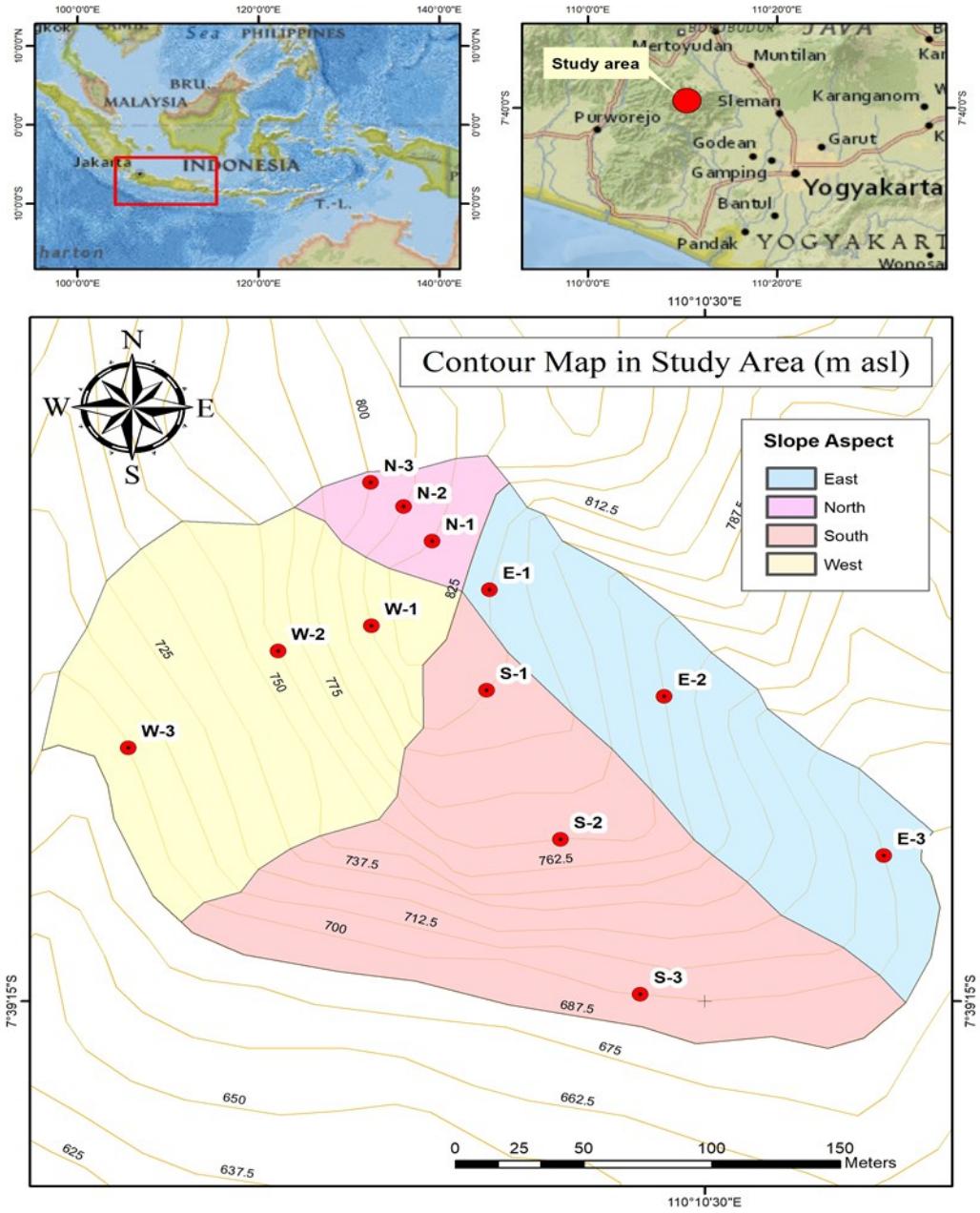


Figure 1. Research area and slope aspect composition.

converted to organic matter by multiplying the percentage of carbon by 1.72; soil total nitrogen was measured by the Kjeldahl method, and cation exchange capacity (CEC) was measured by using the barium chloride–triethanolamine method. Available P was determined by the Bray II method. Exchangeable K, Ca, and Mg were extracted with 1 M NH_4OAc, and determined using a flame photometer and AAS.

Floral Biodiversity Measurement

To estimate the floral species diversity index and to avoid inadequacies caused by the single index, we selected the Shannon-Wiener's diversity index (H), the Simpson index (D), and the evenness index (E) using the following equations:

Shannon-Wiener diversity index (H)

$$H = -\sum_{i=1}^{s} Pi \ln Pi$$

Simpson's diversity index (D)

$$D = 1 - \sum_{i=1}^{n} P_i^2$$

Table 1. Description of study plots.

Slope Aspect	Sample code	Longitude	Latitude	Elevation (m asl)	Description of the location
South	S-1	110° 10' 27,249" E	7° 39' 10,505" S	814	Upper Slope
South	S-2	110° 10' 28,182" E	7° 39' 12,661" S	762	Middle Slope
South	S-3	110° 10' 29,188" E	7° 39' 14,902" S	702	Foot slope
East	E-1	110° 10' 27,284" E	7° 39' 9,053" S	814	Upper Slope
East	E-2	110° 10' 29,490" E	7° 39' 10,595" S	781	Middle Slope
East	E-3	110° 10' 32,257" E	7° 39' 12,896" S	717	Foot slope
West	W-1	110° 10' 25,795" E	7° 39' 9,574" S	814	Upper Slope
West	W-2	110° 10' 24,619" E	7° 39' 9,939" S	767	Middle Slope
West	W-3	110° 10' 22,730" E	7° 39' 11,340" S	700	Foot slope
North	N-1	110° 10' 26,559" E	7° 39' 8,349" S	832	Upper Slope
North	N-2	110° 10' 26,200" E	7° 39' 7,848" S	800	Middle Slope
North	N-3	110° 10' 25,784" E	7° 39' 7,502" S	812	Foot slope

Index of evenness (E)

$$E = H/\ln S$$

where $P_i = N_i/N$, P_i is the proportion of individuals found in the i-th species, S is the total number of species, and N is the total number of individuals of all species present (Zhang et al. 2022).

Data Analysis

A one-way analysis of variance (ANOVA) was used to test the effect of slope aspect (north, east, south, and west) on soil chemical properties and floral biodiversity indices at a 5 % significance level. When significant differences were detected, the means were compared using the least significant difference (LSD) test. All statistical analyses were performed using R software version 4.5.1 for Windows. Correlations among microclimate, soil chemical properties, and floral biodiversity indices were analysed using Pearson's correlation coefficients and visualised in a correlogram generated with the corrplot package

RESULTS AND DISCUSSION

Microclimate at Various Aspects

The topographical orientation of a slope plays a crucial role in determining its interaction with solar radiation, which subsequently influences air temperatures, as depicted in Figure 2A and 2B. East-facing slopes experience higher air temperatures due to prolonged morning solar exposure, while west-facing slopes have lower temperatures owing to reduced afternoon solar radiation. Factors such as cloud cover minimises radiation variations, and high soil moisture or canopy cover, which alter the conversion of shortwave radiation to latent heat flux rather than sensible heat flux, significantly modify these effects (Méndez-Toribio et al. 2016). The temperature difference between east and west-facing slopes ranges from 1 to 4 °C. The north-facing slope receives substantial solar radiation due to the geographical orientation of the Menoreh Highland in the southern hemisphere. However, statistically analysing solar radiation levels between north and south-facing slopes reveals no significant distinction.

The slope aspect plays a pivotal role in shaping air humidity, as illustrated in Figure 2. C. According to the data presented, a discernible gradient in relative humidity is observed, with the east-facing slope exhibiting the lowest levels, followed by the north, west, and south-facing slopes in sequence. This humidity pattern can be ascribed to solar radiation disparities; reduced solar exposure on south and west-facing slopes limits evapotranspiration, thereby increasing air humidity. Conversely, elevated solar radiation on north and east-facing slopes leads to higher temperatures and evapotranspiration

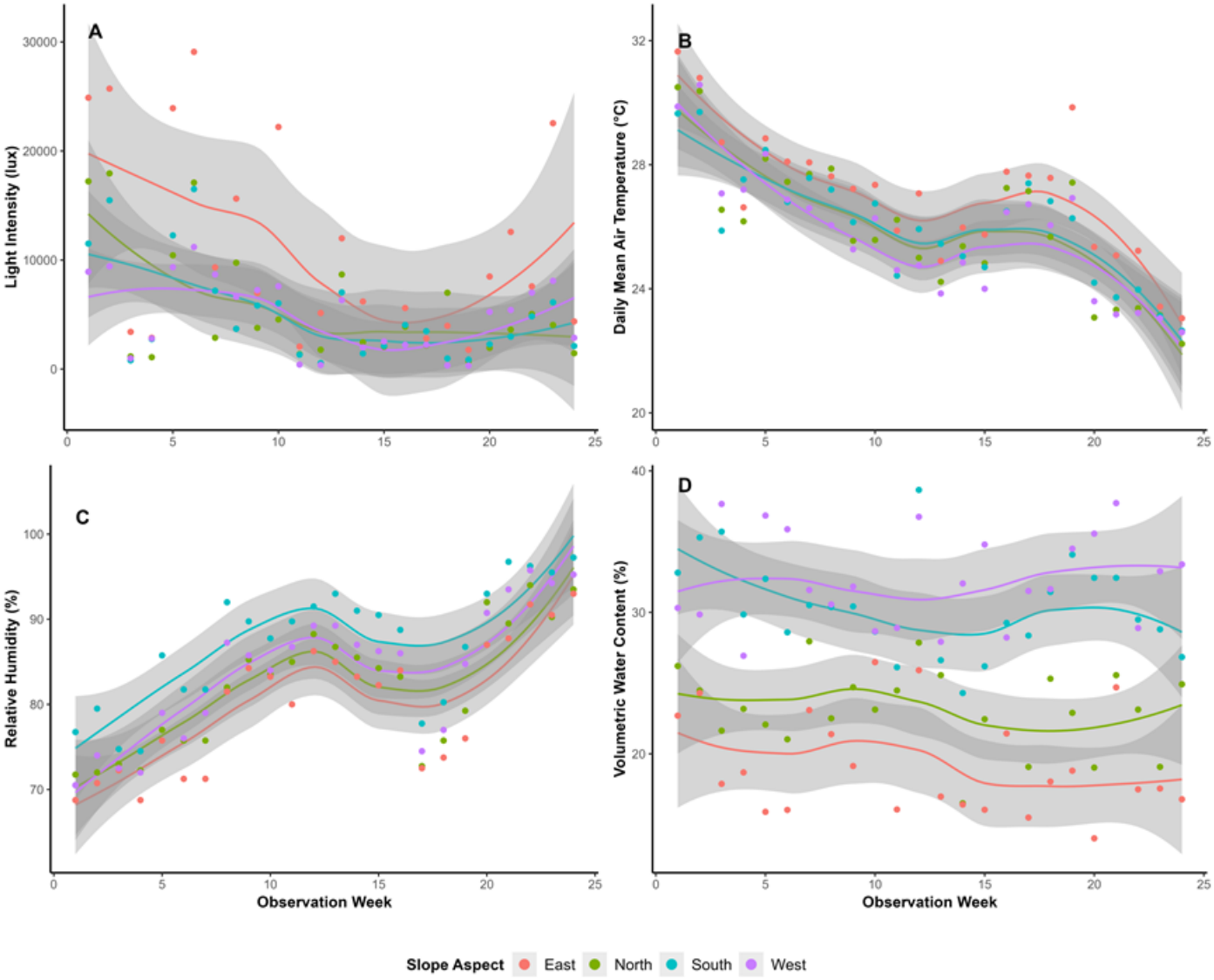


Figure 2. Microclimate condition of each slope. (A) Light intensity, (B) Daily mean air temperature, (C) Relative humidity, and (D) Soil Gravimetric Water Content.

rates, resulting in lower air humidity levels. Moreover, the slope aspect has a significant influence on the soil's gravimetric moisture content. Specifically, south and west-facing slopes, characterised by diminished solar radiation and lower temperatures but higher humidity levels compared to their east and north-facing counterparts, experience reduced rates of soil moisture evaporation. Consequently, these conditions lead to elevated levels of soil gravimetric moisture content. In contrast, the warmer soil temperatures on east and north -facing slopes enhance soil moisture evaporation rates, resulting in lower soil moisture content. Based on the microclimatic variations, the slopes can be categorised into dry slopes (north and east) and humid slopes (south and west), highlighting the profound impact of slope aspect on both air humidity and soil moisture dynamics.

Soil Chemical Properties

The moisture status of different slope aspects has a significant impact on soil pH (Table 2). East and north-facing slopes have a significant effect on increasing soil temperature, contributing to the denaturation of organic acids, increasing soil pH (Onwuka 2018). Research conducted in the Manang province, Nepal (Måren et al. 2015) showed that the low intensity of light reaching the slopes causes high soil moisture levels. An excess of soil moisture is

responsible for the reduction in soil pH, primarily attributed to increased leaching of bicarbonates. Moisture-abundant slopes, specifically the western and southern aspects, contain higher levels of organic matter compared to drier slopes (Table 2). This disparity contributes to elevated soil organic carbon content and cation exchange capacity on these moist slopes, as noted by Murphy (2015). The rate of mineralization and immobilization of organic matter tends to be slower at low temperatures and high humidity. Such conditions favour the activity of microorganisms, and soil fauna are concentrated on slopes with a humid microclimate.

Research by Chen et al. (2016) in the Alpine ecosystem of northwestern China revealed that shaded slopes have higher soil organic carbon and total nitrogen stocks due to varying solar radiation, near-surface temperatures, evaporative demand, and soil moisture. Additionally, cation exchange capacity increases with higher levels of organic matter (Murphy 2015). The decomposition rate of soil organic matter is influenced by a combination of air temperature and soil moisture (Sierra et al. 2015). Moist slopes experience slower organic matter decomposition due to lower air and soil temperatures, as well as higher soil moisture, resulting in more durable organic matter. Conversely, warm slopes experience faster organic matter decomposition due to higher air and soil temperatures, as well as lower soil moisture, which depletes existing organic matter reserves more rapidly. Consequently, there are variations in nitrogen mineralisation across different slope aspects (Table 2).

Statistical analysis results for P_2O_5, K_2O, Ca, Mg, and S (Table 3) demonstrate significant differences between slope aspects. Specifically, soils on humid slopes with low gradients exhibit distinct P_2O_5 differences compared to those on warm slopes with moderate values. Similar trends are observed in total potassium content, with low content on cold slopes and moderate levels on warm slopes. The result aligned with previous research by Zhang et al. (2014), which indicates that warmer slopes have higher total phosphorus and potassium levels. The available P and K nutrient status on the slopes of the Springerville Mountains is influenced by slope aspect, with south-facing slopes exhibiting homogeneous vegetation, high evapotranspiration rates, and elevated available P and K levels. In contrast, north-facing slopes exhibit heterogeneous vegetation and lower evapotranspiration rates, resulting in reduced available P and K levels. P and K in the soil become available through a diffusion process that depends on the soil moisture level, solution concentration, and the rate of organic matter decomposition. Soils with high temperatures have high P and K availability because the release of P and K from organic matter is facilitated quickly by high temperatures and rapid decomposition (Blagodatskaya et al. 2016; Conant et al. 2011). However, if soil moisture does not fulfil the diffusion process, soil P and K will be fixed by soil colloids, resulting in low availability but high total content.

Regarding Ca, Mg, and S levels, statistical analysis (Table 3) reveals that humid slopes have lower content than dry slopes. The high Ca and Mg content at the study site is likely due to the type of parent rock, which originates from calcic sedimentation and flysch (Yamani & Akbarian 2013). These rocks are included in the Kebobutak Formation (Tmok), which is mostly a bedrock formation in the Menoreh hills. Calcic and flysch sedimentation rocks originate from the uplifted deep sea, so they still contain rock fragments with high Ca and Mg. Recent studies by Abdalrahem et al. (2024) and Liu et al. (2024) confirmed that Ca and Mg concentrations vary significantly with slope aspect and depth, supporting the observed pattern in our site. More recently, Zhang et al. (2024) found that micro-topography and water availability control organic S mineralisation in subtropical soils, providing a parallel mechanism to our observations of higher organic sulphur accumulation on shaded (cold) slopes. Consequently, on cold slopes, the formation rate of organic sulphur in the soil increases, resulting in a higher accumulation of organic sul-

Table 2. Component pH H_2O, soil organic matter, soil organic carbon, total nitrogen, C/N ratio, and cation exchange capacity in each slope aspect.

Slope Aspect	pH H_2O	SOM (%)	SOC[1] (%)	TN (%)	C/N Ratio	CEC (cmol (+)kg^{-1})
East	6.83 a	1.77 b	0.89 b	0.167 c	7.41 a	28.84 b
North	6.67 a	1.61 b	0.93 b	0.163 c	5.80 b	24.41 b
South	6.22 b	2.54 a	1.49 a	0.232 b	5.59 b	32.30 a
West	6.38 b	2.84 a	1.63 a	0.302 a	5.41 b	33.90 a
CV (%)	7.5	3.78	10.71	8.57	23.2	2.46

Note: [1]data is transformed using f (x) = (√□); the number shown is the average, followed by the same notation, which is not different by LSD Fisher (5 %). Abbrev: SOM (Soil Organic Matter), SOC (Soil Organic Carbon), TN (Total Nitrogen), CEC (Cation Exchange Capacity)

Table 3. Total phosphorus, total potassium, available Ca, Mg, and S of soil in each slope aspect.

Slope Aspect	Total P (mg kg^{-1})	Total K (mg kg^{-1})	Ca (meq 100 g^{-1})	Mg (meq 100 g^{-1})	S (meq 100 g^{-1})
East	136.3 a	234.5 a	19.55 a	3.60 a	5.94 b
North	114.8 b	221.2 a	19.10 a	3.41 a	6.36 ab
South	107.8 c	200.2 b	13.36 b	2.09 b	6.44 ab
West	106.2 c	185.8 b	11.26 b	2.16 b	6.81 a
CV (%)	2.87	1.35	2.62	2.86	1.62

Note: the number shown is the average, followed by the same notation, which is not different by LSD Fisher (5 %).

phur in the soil.

The pattern of soil physicochemical characteristics tends to be higher on the southern and western slopes or moist slopes. Both slope directions facilitate greater nutrient availability, sufficient water content, and microclimatic conditions suitable for plant growth. Thus, the conditions resulting in relatively more variations in plant species were found on the southern and western slopes. Variations in plant species also correlate with variations in soil fauna and microorganisms. Although the southern and western slopes are pretty suitable for supporting plant growth, the maximum solar radiation intensity is higher on the suitable northern and eastern slopes. Finally, slope aspect is one of the important considerations in arranging the types of agricultural or plantation crops that require optimum solar radiation.

Floral Biodiversity in Four Different Aspects

Several studies have indicated a relationship between biodiversity and slope aspect in tundra, subtropical, and arid regions. However, research in tropical areas has been scarce due to the perception that slope aspect has minimal impact on plant life. This study focused on an untouched hillside, aiming to provide an accurate depiction of the influence of slope aspect. Based on Figure 3, it is evident that slope aspect affects biodiversity indices, evenness, and richness. The Simpson index (D) and Shannon-Wiener index (H) were utilised. The D value on the western slope differed significantly from that on the other slopes. Similar patterns were observed in H values, where the western slope exhibited the lowest diversity compared to other slopes. The northern and southern slopes showed no significant differences, but they were significantly different from the eastern slope, which had the highest H value. Regarding evenness (E), only the western slope significantly differed from the others.

Analysing D, H, and E values, the western slope exhibited the lowest diversity with a relatively limited species variety, as depicted in Figure 3 under species richness (R). Further categorisation by plant type (Figure 4) revealed a dominance of tree species, including *Syzygium aromaticum* (17.51 %),

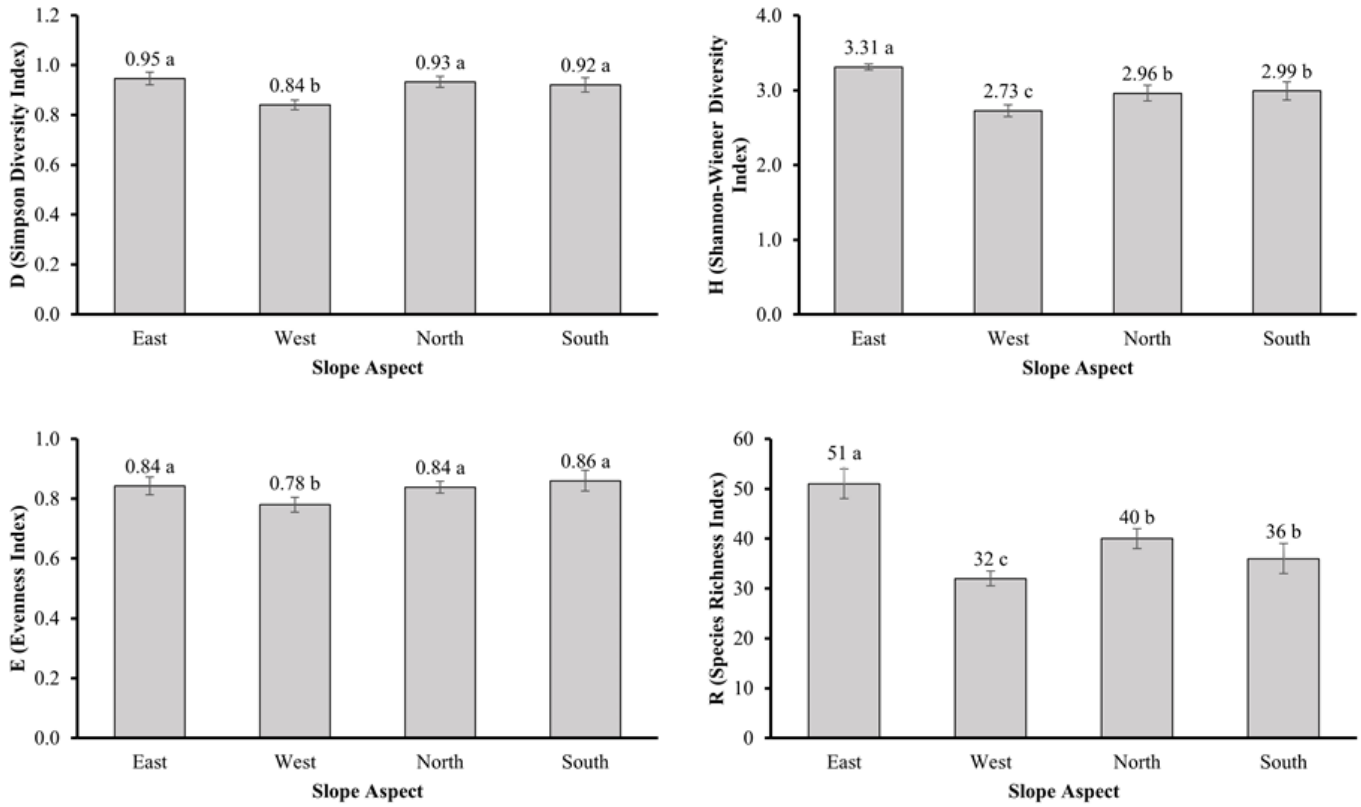


Figure 3. Floral biodiversity characteristics on different slope aspects (mean ± SE).

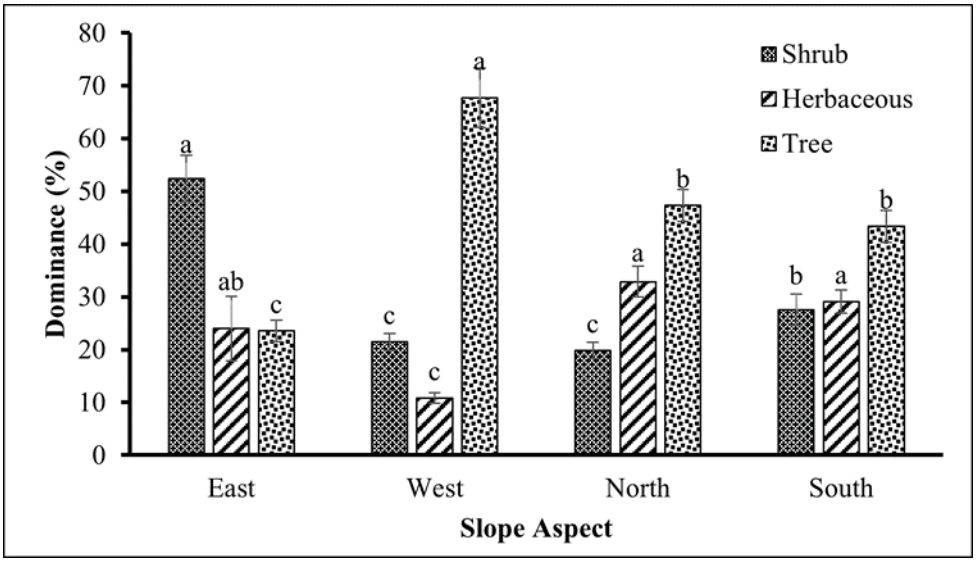


Figure 4. Plant type dominance on different slope aspects (mean ± SE).

Arenga pinata (14.98 %), and *Gnetum gnemon* (11.55 %) on the western slope. Conversely, the eastern slope showcased the highest biodiversity, indicated by the highest H value (3.31). Although its D value (0.95) did not differ significantly from that of the northern (0.93) and southern slopes (0.92), the eastern slope stood out with the highest species richness (51) compared to the statistically similar northern and southern slopes (40 and 36, respectively). Shrubs dominated the eastern slope (Figure 4), with key species being *Mimosa pudica* (18.01 %), *Oxalis barrelieri* (17.78 %), and *Amomum compactum* (9.93 %) (Figure 5).

The biodiversity characteristics of the northern and southern slopes were relatively similar, with statistically identical D, H, E, and R values (Figure 3). The main distinction lay in the shrub dominance on the northern slope, which was lower than that on the southern slope. Key species on the

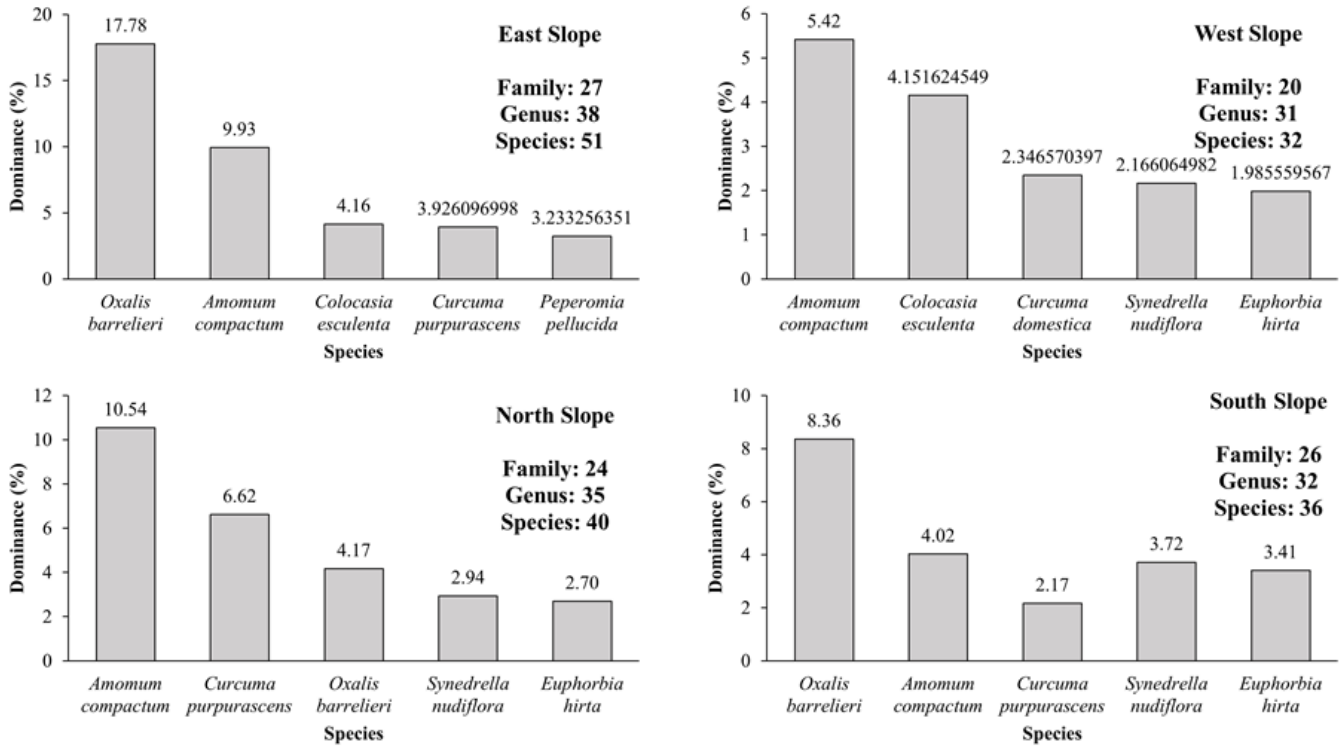


Figure 5. Dominance and composition of plant species, genus, and family on different slope aspects (mean ± SE).

northern slope included *Syzygium aromaticum* (14.61 %), *Amomum compactum* (9.93 %), and *Gnetum gnemon* (7.39 %). The northern slope was predominantly tree-dominated, exhibiting similarities with the western slope. In contrast, the southern slope was dominated by species such as *Peperomia pellucida* (7.85 %), *Syzygium aromaticum* (7.62 %), and *Oxalis barrelieri* (6.24 %), displaying a tree population similar to that of the eastern slope but less dense than the northern slope.

Correlation between Microclimate and Soil Chemical Properties to Biodiversity

The direction of sunlight plays a crucial role in determining the microenvironmental conditions of an area, consequently influencing plant diversity. The Menoreh Mountains, situated within Indonesia, fall within the Tropical Zone, located between 23.5 degrees north and south latitude. Sunlight in these regions tends to be more consistent throughout the year, providing favourable conditions for a variety of tropical plants (Tonkin et al. 2017). Microclimatic influences, topography, soil structure, and vegetation cover can modify the direction and intensity of sunlight in an area (Bramer et al. 2018). For instance, valleys may have different sunlight patterns compared to hills or plateaus. Under large trees or within forest environments, a shadow zone exists where direct sunlight does not reach the ground. In the penumbra zone, sunlight is reduced, leading to higher temperatures and humidity (Halama et al. 2018). Some plants may be better adapted to direct sunlight, while others prefer semi-bright conditions or partial shade (Mathur et al. 2018). Slopes facing the sun tend to receive more sunlight compared to those facing the opposite direction, potentially influencing the types of plants that can thrive on each slope.

Figure 6 illustrates the correlation between microclimate variables, soil chemical properties, and biodiversity indices. The Shannon-Wiener index (H) exhibits a strong positive correlation with solar radiation and air temperature, while showing a negative correlation with humidity and soil water content. The Simpson index (D) follows a similar pattern to index H but lacks a

correlation with humidity. Evenness shows no correlation with any microclimate variables. The western slope is characterised by limited insolation, receiving adequate insolation for only about ±5 hours per day due to frequent afternoon fog in the Menoreh Highland region. This lack of sunlight results in more humid microclimatic conditions on the western slope, characterised by higher soil moisture availability. Consequently, this creates suitable conditions for tree growth, leading to their dominance over other plant types. Invasive tree species can suppress the development of shrubs and herbaceous types, resulting in low diversity on the western slope (Gaertner et al. 2014). In contrast, the eastern slope receives higher insolation, causing increased air temperature, reduced air humidity, and lower surface soil moisture content. Plants thriving here are predominantly shrubs with relatively shallow root systems compared to tree plants. The eastern side has fewer trees, allowing sunlight to directly reach shrub species without tall tree canopies obstructing it. Additionally, the eastern side appears to be in a succession stage have been previously utilised as a clove plantation, which was subsequently abandoned.

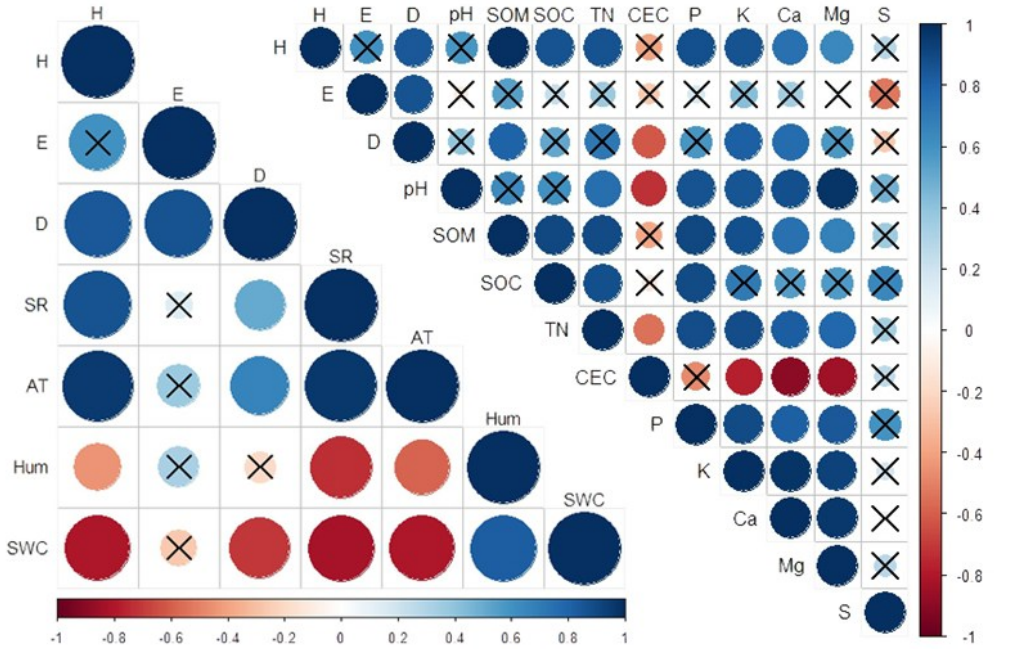


Figure 6. Correlogram of diversity indices, soil chemical properties, and microclimate variables. Abbreviations, H (Shannon-Wiener Index), E (Evenness), D (Simpson Index), SR (Solar Radiation), AT (Air Temperature), Hum (Humidity), SWC (Soil Water Content), pH (pH H_2O), SOM (Soil Organic Matter), SOC (Soil Organic Carbon), TN (Total Nitrogen), CEC (Cation Exchange Capacity), P (Soil Phosphorus Content), K (Soil Potassium Content), Ca (Soil Calcium Content), Mg (Soil Magnesium Content), S (Soil Sulphur Content).

The findings presented in the research conducted by Yang et al. (2020) in a semiarid region indicate notable ecological patterns. Specifically, the study observed increased biomass, height, and differences in β diversity, alongside decreased density and coverage differences in relatively wet sites. Interestingly, a contrasting trend was observed in α diversity. In a separate study conducted in the tropical region of Mount Pinatubo, Philippines, by Marler and Del Moral (2018), the influence of slope aspect on species composition was examined. The research revealed a strong correlation between slope aspect and species distribution, with Fabaceae predominantly found on south-facing slopes. Furthermore, plant communities such as vines, grasses, and forbs, typical of habitats with higher sunlight exposure, were more abundant on south-facing slopes. In contrast, trees and ferns were prevalent on

north-facing slopes. Another noteworthy study by Jin et al. (2023) highlighted the impact of soil water content (SWC) on vegetation structure in secondary succession of primary forests. It was observed that the north-facing slopes exhibited greater tree density compared to the south-facing slopes. In general, soil moisture plays a crucial role in shaping the vegetation structure of plants, including shrubs. Adequate soil moisture is essential for the growth and development of plants. When the soil becomes dry due to increased evaporation, it can have significant effects on the vegetation structure of shrubs. Interestingly, recent studies have reported comparable findings. Yang et al. (2020) found that variations in moisture availability across slope aspects strongly influenced β-diversity patterns but not necessarily overall vegetation density or coverage. Similarly, Cheng et al. (2023) observed that elevation, aspect, and slope degree significantly affected vegetation composition and β-diversity, while having no substantial impact on species richness. Likewise, Tyagi et al. (2023) demonstrated that although aspect and slope position influenced species distribution and water relations, the overall vegetation structure remained relatively stable. These studies collectively suggested that while topographic factors such as slope aspect and altitude are key determinants of β-diversity and species composition, their influence on vegetation structure may be limited or context-dependent.

In Figure 6, correlations between biodiversity indices and soil chemical parameters are depicted. Regarding land cover diversity, there is no correlation between evenness and soil chemical properties. A noteworthy positive correlation emerged between the Shannon-Wiener index and multiple soil parameters, including soil organic matter, soil organic carbon, total nitrogen, phosphate, potassium, calcium, and magnesium. This finding is similar with previous research conducted by Demeter et al. (2021), where the H index of shrubs is strongly positively correlated with soil ammoniacal nitrogen, total nitrogen, soil calcium content, and humus (soil organic matter and soil organic carbon), whilst H index of grounds is strongly correlated to total nitrogen, humus, soil ammoniacal nitrogen, and total potassium. Other research by Nadeau and Sullivan (2015) found that the H index of tree species was positively correlated with the C/N ratio, while herb structural richness was positively correlated with the soil fertility index and P concentration. Different results found by Zhang et al. (2022) show that there are no soil chemical properties correlated with plant diversity in the Tibetan Plateau. The augmentation in these parameters can be attributed to a substantial increase in root quantity and litter diversity (Castro-Díez et al. 2012). Soil organic matter serves as a reservoir of nutrients and energy for plants. Organic matter enhances soil structure, water retention, and nutrient availability. It provides a favourable environment for plant roots and supports diverse microbial communities. Adequate levels of essential nutrients, such as nitrogen, phosphorus, potassium, calcium, and magnesium, are vital for plant growth and development. Soils rich in these nutrients provide the necessary foundation for a diverse range of plant species to thrive (Long et al. 2012; Wu et al. 2017). Plants, in turn, benefit from these improved soil conditions, leading to increased biodiversity as various species can establish and grow effectively.

CONCLUSIONS

Slope aspect had a significant influence on soil properties and plant diversity in the Menoreh Highland. Humid slopes supported soils with higher organic matter, nitrogen, and cation exchange capacity, fostering shrub-dominated communities. Conversely, dry slopes exhibited lower fertility and a greater dominance of trees. These findings underscore the critical role of microclimate in shaping tropical ecosystems and warrant further investigation in other regions.

AUTHOR CONTRIBUTION

Y.A. and J.H.P. designed the research, supervised the entire process, and wrote the manuscript. G.I.J., A.N., A.H., and F.R.F. collected and analysed the data, H.M.P. did the project administration, and A.B.P. did the data validation.

ACKNOWLEDGMENTS

The researchers would like to express their sincere gratitude to the Gerbosari village government for their invaluable support and permission to conduct this research within their jurisdiction. Special thanks also go to the field extension officer for their guidance and assistance throughout the study. Their contributions were essential to the successful completion of this research.

CONFLICT OF INTEREST

There is no conflict of interest regarding the research or the funding for the study.

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