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Characterization of Spores and Diversity of Pteridophyta in the Waterfall Area

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Abstract

Ferns (Pteridophyta) are an important component of tropical forest ecosystems, playing a role in maintaining humidity, preventing erosion, and having ecological and economic value. The waterfall area has a microclimate that supports the growth of ferns, making it a promising site for studying biodiversity and characterizing spores. This study aims to identify the diversity of Pteridophyta species, analyze community structure, and describe spore characteristics as a basis for identification and classification. The method used was exploratory descriptive with a mixed methods approach through the establishment of transects and plots at three observation stations, measurement of environmental parameters, and observation of spores in the laboratory using a trinocular microscope. The results showed that 21 species of ferns from 8 families were found, with a Shannon-Wiener diversity index of 2.76, which indicates a moderate level of species diversity. The species *Adiantum tenerum* had the highest dominance, while *Pteris vitata* had the lowest. Spore characterization in 12 species showed variations in shape, size, color, and aperture type, dominated by monolete and trilete. These results confirm the importance of spore characteristics as taxonomic features in Pteridophyta studies.

1. INTRODUCTION

Ferns (Pteridophyta) are a group of vascular plants that are classified as corm plants because their organs have clear morphological differentiation into roots, stems, and leaves. Ferns are plants that do not produce seeds and reproduce mainly through spores [1]. In terms of habitat, ferns can be

found in terrestrial, aquatic, epiphytic, and lithophytic environments. Their ability to adapt to diverse environmental conditions enables them to occupy a wide range of habitats [2]. Ferns play an important role in forest ecosystems by protecting the soil from erosion and playing a role in the formation of humus

as well as being important for humans as a potential food source [3].

Ferns are commonly found in tropical climates with humid environmental conditions, ranging from open areas, primary forests to secondary forests, lowlands and highlands, as well as aquatic areas such as riverbanks and humid grasslands [4]. One habitat that is very conducive to the growth and diversity of ferns is waterfall areas [5]. Waterfalls are open green spaces with relatively healthy ecosystems, mountainous topography, and high humidity levels, making them capable of supporting a variety of fern species and offering potential as sites for exploratory and characterization research [6].

The waterfall area covers approximately 23 hectares and features rocky terrain and humid environmental conditions, which support the growth of various types of ferns. This area is part of a forest park ecosystem and provides diverse habitats for pteridophytes. Therefore, the waterfall area has the potential to serve as a research site for studying fern diversity and spore characteristics, which form the basis for understanding the reproduction and classification of ferns (Pteridophyta).

Characterization of spores Pteridophyta is very important for understanding species diversity and distribution. The morphological structure of spores, including shape, size, color, and aperture type, provides important information in the process of identifying and classifying ferns [7]. Therefore, research on the characterization of spores and the diversity of ferns (Pteridophyta) has great potential to contribute scientifically to the documentation and understanding of local biodiversity.

2. MATERIALS AND METHODS

This study was conducted from January to This study was conducted in the waterfall area, ranging from the ticket booth entrance to the main waterfall area. The waterfall is located on the slopes of Mount Welirang. This study employed a descriptive-exploratory research design using a mixed-methods approach,

which combines quantitative and qualitative methods. Data collection involved identifying the characteristics of the spores under study and clearly describing the types of ferns as qualitative data. Meanwhile, quantitative data were derived from the number or value of biodiversity [8]. The quantitative data analysis used the Shannon-Wiener diversity index ($\hat{H}$) to determine the species diversity of Pteridophyta. This index was calculated using the following formula [9].

Diversity Index

$$\hat{H} = -\sum P_i \times \ln P_i$$

Explanation:

$\hat{H}$: Diversity index

P_i : n_i/N , ratio between the number of individuals of species 1 and the total number

N_i : Number of individuals of species 1

N : Total number of individuals.

From the above formula, we can see the criteria for the diversity index ($\hat{H}$), such as if $\hat{H} < 1$, then the diversity is said to be low; if $\hat{H} = 1-3$, then the diversity is said to be moderate; and if $\hat{H} > 3$, then the diversity is said to be high.

Importance Value Index

The Importance Value Index (IVI) is used to determine the relative dominance of each Pteridophyta species within the study area. The IVI is calculated based on relative density (RD) and relative frequency (RF) [10].

1) Density (D) of a species:

$$D = \frac{\text{Number of individuals in the sample plots}}{\text{Total area of sample plots}}$$

2) Relative Density (RD):

$$RD = \frac{\text{Density of a species}}{\text{Density of all species}} \times 100\%$$

3) Frequency (F):

$$F = \frac{\sum \text{Plots where a species is found}}{\sum \text{Sample plots}}$$

4) Relative Frequency (RF):

$$RF = \frac{\text{Frequency of a species}}{\text{Frequency of all species}} \times 100\%$$

5) Importance Value Index:

$$IVI = RD + RF$$

This study also applies the Embedded Design method, which combines the ex-post facto method as the primary approach and the qualitative method as the secondary approach. The Embedded Design method aims to collect qualitative and quantitative data simultaneously with one type of data supporting the other. The focus of this study is not on the order of collection, but on the importance of the data collected. The following are the data collection techniques used in this study.

Preliminary Study

This preliminary study aims to identify the presence and characteristics of fern (Pteridophyta) spores in the waterfall area. These preliminary activities include habitat observation, initial sampling, and documentation. The results of this preliminary study are expected to provide an initial

overview of the diversity and characterization of Pteridophyta spores.

Determination of Stations

Before determining the stations for this study, field observations must first be conducted. These field observations were used to assess the distribution of fern species (Pteridophyta), thereby facilitating the selection of observation points and stations. Based on the tracking conducted by the researcher, this study utilized three stations, each consisting of 10 plots measuring 2×2 meters, spaced 10 meters apart, with each station spaced 100 meters apart. The locations of the stations in this study are divided into three areas: Station 1 is near the waterfall ticket booth entrance, Station 2 is in the open park area, and Station 3 is in the main area of the waterfall. An illustration of the stations and plots in this study can be seen in Figure 1 below.

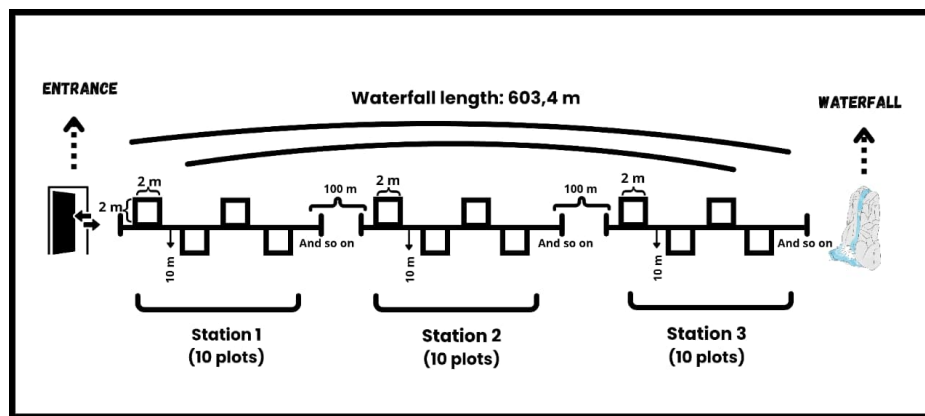


Figure 1. Illustration of the research path

Environmental Parameter Measurement

The environmental parameters measured in this study included temperature, air humidity, soil pH, soil moisture, and light intensity. The parameters observed in this study included the shape, color, size, and type

of aperture of Pteridophyta spores, as well as the diversity of ferns (Pteridophyta) in the waterfall area. The results of the environmental parameter measurements in the Kakek Bodo Waterfall area are presented in Table 1 below.

Table 1. Measurement of environmental parameters in the waterfall area

Environmental	Station 1	Station 2	Station 3	Average
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Factors	Repetition			Repetition			Repetition			
	I	II	III	I	II	III	I	II	III	
Temperature (°C)	29.6	30.3	25.1	27.7	22.1	26.8	29.1	27.2	26.7	27.2
Air humidity (%)	61	43	70	48	86	62	73	61	74	64.2
Light intensity	1071	2701	105	4292	3262	8258	4809	1270	2723	3166
Soil pH	6	2	3	2	5	2	3	1.8	2	3.1
Soil moisture	4.9	6.8	6.4	6.8	5.5	6.6	6.3	6.7	6.6	6.3

Sampling

Sampling was conducted to collect ferns (Pteridophyta) that produce spores, which were used as samples for identification and observation of spore characteristics. Before sampling began, the researcher prepared the tools and materials needed for the collection, preparation, and observation of spores. The tools used included a thermometer to measure temperature, a hygrometer to measure air humidity, a pH meter to measure soil pH, a soil tester to measure soil moisture, and a lux meter to measure light intensity. A cell phone was used to document the samples and research results, while plastic sample bags were used to hold the fern samples and label paper was used to identify the sample types. The Alpine Quest app was used to mark the sampling routes. Spore observation was conducted using a trinocular microscope connected to an Optilab camera and a laptop, while the Optilab Viewer 4 application was used to capture and save the observation documentation. A razor blade was used to scrape the sori from fern leaves, a sterile toothpick was used to draw up the glycerin solution, a microscope slide was used to place the sori, a cover slip was used to cover the slide, and a beaker was used to hold the 99.7% pure glycerin solution. The materials used consist of ferns that produce spores and a 99.7% pure glycerin solution. The ferns serve as observation samples, while the glycerin solution is used to enhance the visibility of the spores and help separate them from the sori clusters.

Sampling was conducted by establishing transect lines starting from the entrance and extending to the main site of Kakek Bodo

Waterfall in Prigen. Three observation stations were established at the study site, with each station consisting of 10 plots and a distance of 100 m between stations. At each station, 2 × 2 m plots were laid out in a zigzag pattern along the transect line, with a distance of 10 m between plots. Samples of each fern species found in each plot were then collected for identification and further observation. The collected samples were placed in plastic sample bags and labeled to indicate the species, particularly for samples that could not be immediately identified at the study site. The collected fern samples were subsequently taken to the laboratory for observation of spore morphological characteristics.

Observation of spore characteristics was conducted using fern leaves collected in the field that bore sori. The sori were scraped off using a razor blade and then placed on a microscope slide. Next, a single drop of 99.7% pure glycerin solution was added to the sori. The glycerin solution was used sparingly to prevent the slide from becoming too cloudy, which would interfere with the observation process. The slide was then covered with a cover slip by gently sliding it into place to help rupture the sporangia so that the spores inside could be released. The prepared slides were then observed using a trinocular microscope connected to an Optilab camera and a laptop. Observations were conducted in stages, starting from the lowest magnification to the highest, to obtain clearer characteristics of the spores. The observation results were documented and saved using the Optilab Viewer 4 application. The observed spore characteristics included shape, color, size, and type of spore aperture. All observation results

were then recorded on an observation sheet for subsequent use in the identification process and data analysis.

Sample Identification

The identification of the results of this study was recorded on the observation sheet according to the results of field observations, then similarities in characteristics between fern species were sought to facilitate the identification process. Next, from the results of the identification, the fern diversity index and importance value index were calculated so that the differences between each species could be determined.

Meanwhile, to determine the characteristics of the fern spores observed at the Biology Education Laboratory of Nahdlatul Ulama University in Pasuruan, they were examined under a trinocular microscope using an Optilab camera connector and digital device. The characteristics of several spores were then recorded and examined, including spore shape, spore color, spore size, and spore aperture type.

3. RESULTS

Identification and Composition of Fern Species in the Waterfall Area

Total of 21 fern species belonging to the class Polypodiopsida were found in the waterfall area (Table 2). These species comprise two orders, namely Polypodiales and Salviniales, and eight families, namely Athyriaceae, Aspleniaceae, Davalliaceae, Deenstaedtiaceae, Polypodiaceae, Pteridaceae, Thelypteridaceae, and Marsileaceae. The Pteridaceae family has the largest number of species, with seven, while the Aspleniaceae family consists of five species (Table 2).

The fern species from the Pteridaceae family found here include *Adiantum hispidulum* (A), *Adiantum philippense* (B), *Adiantum tenerum* (C), *Pteris biaurita* (O), *Pteris ensiformis* (P), *Pteris longipinnula* (Q), and *Pteris vitata* (R). Meanwhile, the Aspleniaceae family consists of *Christella arida* (E), *Christella dentata* (F), *Christella parasitica* (G), *Diplazium amplissimum* (I), and *Diplazium esculentum* (J). Other fern species belong to the families Athyriaceae, Davalliaceae, Deenstaedtiaceae, Polypodiaceae, Thelypteridaceae, and Marsileaceae (Figure 2)

Table 2. Identification and composition of fern (Pteridophyta) species found in the waterfall area

No.	Class	Order	Family	Genus	Species
1.	Polypodiopsida	Polypodiales	Athyriaceae	Athyrium	<i>A. filix-femina</i>
2.			Aspleniaceae	Christella	<i>C. arida</i>
3.					<i>C. dentata</i>
4.					<i>C. parasitica</i>
5.				Diplazium	<i>D. amplissimum</i>
6.					<i>D. esculentum</i>
7.			Davalliaceae	Davallia	<i>D. trichomanoides</i>
8.			Deenstaedtiaceae	Microlepia	<i>M. speluncae</i>
9.			Polypodiaceae	Nephrolepis	<i>N. cordifolia</i>
10.				Pleocnemia	<i>P. irregularis</i>
11.				Schellolepis	<i>S. subauriculata</i>
12.			Pteridaceae	Adiantum	<i>A. hispidulum</i>
13.					<i>A. philippense</i>
14.					<i>A. tenerum</i>
15.				Pteris	<i>P. biaurita</i>
16.					<i>P. ensiformis</i>
17.					<i>P. longipinnula</i>

No.	Class	Order	Family	Genus	Species
18.					<i>P. vitata</i>
19.			Thelypteridaceae	Thelypteris	<i>T. immersa</i>
20.					<i>T. irregularis</i>
21.		Salviniales	Marsileaceae	Marsilea	<i>M. crenata</i>



Figure 2. Diversity species : *Adiantum hispidulum* (A) *Adiantum philippense* (B) *Adiantum tenerum* (C) *Athyrium filix-femina* (D) *Christella arida* (E) *Christella dentata* (F) *Christella parasitica* (G) *Davallia trichomanoides* (H) *Diplazium amplissimum* (I) *Diplazium esculentum* (J) *Marsilea crenata* (K) *Microlepia speluncae* (L) *Nephrolepis cordifolia* (M) *Pleocnemia irregularis* (N) *Pteris biaurita* (O) *Pteris ensiformis* (P) *Pteris longipinnula* (Q) *Pteris vitata* (R) *Schellolepis subauriculata* (S) *Thelypteris immersa* (T) *Thelypteris irregularis* (U)

Morphological Characteristics of Fern Spores in the Waterfall Area

Total 21 fern species found in the waterfall area, 12 species produce spores, and their morphological characteristics could be observed (Table 3). The characteristics observed included aperture type, shape, color, and spore size. Based on aperture type, two types of spores were identified: trilete in four species and monolete in eight species. The shapes of the spores included globose,

triangular, ellipsoidal, and kidney-shaped (Table 3).

Globose spores were found in *Schellolepis subauriculata* and *Christella arida*, while triangular spores were found in *Adiantum philippense* and *Pteris vitata*. Ellipsoidal spores were found in *Christella parasitica*, *Diplazium amplissimum*, *Pleocnemia irregularis*, *Diplazium esculentum*, *Christella dentata*, and *Microlepia speluncae*. Meanwhile, kidney-shaped spores were found in *Adiantum hispidulum* and *Davallia trichomanoides*. The colors of the

spores varied, including yellow, brownish-green, dark brown, yellowish-brown, light brown, brownish-green, and light to dark brown.

Spore size varies among species. The largest polar axis (PA) size was found in *Christella arida*, at 81 μm , while the smallest PA size was found in *Microlepia speluncae*, at 31

μm . The largest equatorial axis (EA) size was also found in *Christella arida*, at 86 μm , while the smallest EA size was found in *Microlepia speluncae*, at 23 μm . The observed spore shapes included globose (A–B), triangular (C–D), ellipsoidal (E–J), and kidney-shaped (K–L)

Table 3. Characteristic data of Pteridophyta spores

No	Aperture Type	Shape	Color	Size (μm)		Species name
				PA	EA	
1.	Trilete	Globose	Yellow	39	36	<i>Schellolepis subauriculata</i> ^{A)}
2.			Brownish green	81	86	<i>Christella arida</i> ^{B)}
3.		Triangular	Yellow	64	64	<i>Adiantum philippense</i> ^{C)}
4.				52	55	<i>Pteris vitata</i> ^{D)}
5.	Monolete	Ellipsoidal	Dark brown	58	39	<i>Christella parasitica</i> ^{E)}
6.			Brownish yellow	63	49	<i>Diplazium amplissimum</i> ^{F)}
7.				58	41	<i>Pleocnemia irregularis</i> ^{G)}
8.			Light brown	50	43	<i>Diplazium esculentum</i> ^{H)}
9.		Kidney-shaped	Greenish brown	72	34	<i>Christella dentata</i> ^{I)}
10.			Light brown to dark brown	31	23	<i>Microlepia speluncae</i> ^{J)}
11.			Yellow	74	50	<i>Adiantum hispidulum</i> ^{K)}
12.				69	47	<i>Davallia trichomanoides</i> ^{L)}

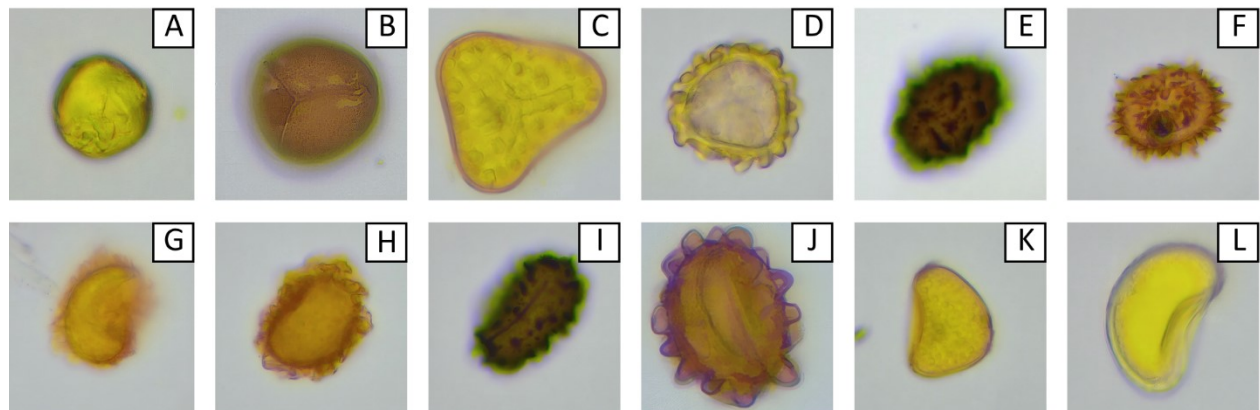


Figure 3. Morphological characteristics of fern spores. Globose spores (A–B), triangular spores (C–D), ellipsoidal spores (E–J), and kidney-shaped spores (K–L).

Fern Diversity Around the Waterfall

Across all research plots, a total of 579 individuals representing 21 species of ferns were found. The Shannon Wiener diversity index was calculated to be 2.76 (Table 4).

Based on the Important Value Index (IVI) calculations, *Adiantum tenerum* had the highest IVI value at 19.24%, followed by *Davallia trichomanoides* at 18.88% and *Thelypteris*

irregularis at 18.72%. The lowest IVI value was found in *Pteris vitata* at 2.72% (Table 5).

Table 4. Pteridophyta diversity Index of Pteridophyta in waterfall area

No.	Species Name	Amount	Pi	LnPi	Pi×LnPi
1	<i>Adiantum hispidulum</i>	6	0.01	-4.57	-0.05
2	<i>Adiantum philippense</i>	41	0.07	-2.65	-0.19
3	<i>Adiantum tenerum</i>	53	0.09	-2.39	-0.22
4	<i>Athyrium filix -femina</i>	24	0.04	-3.18	-0.13
5	<i>Christella arida</i>	8	0.01	-4.28	-0.06
6	<i>Christella dentata</i>	54	0.09	-2.37	-0.22
7	<i>Christella parasitica</i>	26	0.04	-3.10	-0.14
8	<i>Davallia trichomanoides</i>	85	0.15	-1.92	-0.28
9	<i>Diplazium amplissimum</i>	29	0.05	-2.99	-0.15
10	<i>Diplazium esculentum</i>	26	0.04	-3.10	-0.14
11	<i>Marsilea crenata</i>	55	0.09	-2.35	-0.22
12	<i>Microlepia speluncae</i>	6	0.01	-4.57	-0.05
13	<i>Nephrolepis cordifolia</i>	31	0.05	-2.93	-0.16
14	<i>Pleocnemia irregularis</i>	9	0.02	-4.16	-0.06
15	<i>Pteris biaurita</i>	7	0.01	-4.42	-0.05
16	<i>Pteris ensiformis</i>	5	0.01	-4.75	-0.04
17	<i>Pteris longipinnula</i>	14	0.02	-3.72	-0.09
18	<i>Pteris vitata</i>	6	0.01	-4.57	-0.05
19	<i>Schellolepis subauriculata</i>	20	0.03	-3.37	-0.12
20	<i>Thelypteris immersa</i>	24	0.04	-3.18	-0.13
21	<i>Thelypteris irregularis</i>	50	0.09	-2.45	-0.21
Total		579	H	2.76	

Table 5. Importance Value Index (IVI) of Pteridophyta in the waterfall area.

No.	Species name	Amount	Total Area	D	RD	F	RF	IVI
1	<i>Adiantum hispidulum</i>	6	120	0.05	1.04	0.10	2.52	3.56
2	<i>Adiantum philippense</i>	41	120	0.34	7.08	0.30	7.56	14.64
3	<i>Adiantum tenerum</i>	53	120	0.44	9.15	0.40	10.08	19.24
4	<i>Athyrium filix -femina</i>	24	120	0.20	4.15	0.17	4.20	8.35
5	<i>Christella arida</i>	8	120	0.07	1.38	0.07	1.68	3.06
6	<i>Christella dentata</i>	54	120	0.45	9.33	0.33	8.40	17.73
7	<i>Christella parasitica</i>	26	120	0.22	4.49	0.20	5.04	9.53
8	<i>Davallia trichomanoides</i>	85	120	0.71	14.68	0.17	4.20	18.88
9	<i>Diplazium amplissimum</i>	29	120	0.24	5.01	0.20	5.04	10.05
10	<i>Diplazium esculentum</i>	26	120	0.22	4.49	0.13	3.36	7.85
11	<i>Marsilea crenata</i>	55	120	0.46	9.50	0.27	6.72	16.22
12	<i>Microlepia speluncae</i>	6	120	0.05	1.04	0.13	3.36	4.40

13	<i>Nephrolepis cordifolia</i>	31	120	0.26	5.35	0.07	1.68	7.03
14	<i>Pleocnemia irregularis</i>	9	120	0.08	1.55	0.10	2.52	4.08
15	<i>Pteris biaurita</i>	7	120	0.06	1.21	0.17	4.20	5.41
16	<i>Pteris ensiformis</i>	5	120	0.04	0.86	0.10	2.52	3.38
17	<i>Pteris longipinnula</i>	14	120	0.12	2.42	0.30	7.56	9.98
18	<i>Pteris vitata</i>	6	120	0.05	1.04	0.07	1.68	2.72
19	<i>Schellolepis subauriculata</i>	20	120	0.17	3.45	0.03	0.84	4.29
20	<i>Thelypteris immersa</i>	24	120	0.20	4.15	0.27	6.72	10.87
21	<i>Thelypteris irregularis</i>	50	120	0.42	8.64	0.40	10.08	18.72
Total		579	120	4.83	100.00	3.97	100	200.00

4. DISCUSSION

Diversity and Identification of Ferns (Pteridophyta) Species

The diversity of Pteridophyta found indicates that the waterfall area provides suitable habitat conditions for the growth of various fern species. The presence of several taxonomic groups within a single area reflects the existence of microhabitat variations that can be utilized by species with different ecological needs. These variations are related to the area's abiotic conditions, such as humidity, light intensity, soil conditions, and substrate characteristics. Thus, the presence of various Pteridophyta species in the study area can be viewed as an indication that the waterfall habitat provides a heterogeneous environment that supports the sustainability of the fern community.

The patterns of biodiversity identified in this study show similarities to studies conducted in other waterfall areas, but differ in terms of the number of species and family composition. These findings are consistent with a study conducted in the Jurang Nganten Waterfall area in Jepara, which identified 24 species from 11 families, whereas this study revealed a different number of species and family composition [11]. These differences indicate that Pteridophyta communities do not have a uniform composition across all waterfall areas. Such variations may be influenced by differences in

microhabitat conditions, elevation, substrate characteristics, humidity, light intensity, the size of the study area, and the sampling methods employed. This suggests that local habitat characteristics are key factors in determining the composition and diversity of Pteridophyta.

The high representation of Pteridaceae in the Pteridophyta community at the study site is thought to be related to the ecological ability of its members to adapt to diverse habitat conditions. The genera *Adiantum* and *Pteris* found in this study are capable of growing in different environmental conditions, including open, moist, and shaded habitats. Variations in microclimatic conditions in the waterfall area particularly differences in light intensity and humidity across different parts of the area can provide suitable niches for various species within this family. This finding is consistent with a study in the Sekar Pudak Sari Waterfall area, Jombang, which also identified Pteridaceae as one of the families with the highest number of species and noted that members of this family can be found in open, dry, moist, and shaded habitats [12]. These similarities suggest that the ecological flexibility of the Pteridaceae is likely one of the factors contributing to the family's high representation in waterfall habitats.

The Shannon Wiener index value indicates that the Pteridophyta community in the study area has a moderate level of

diversity. This suggests that the community consists of several species with abundances that are not entirely uniform. Thus, the level of diversity observed is influenced not only by the number of species but also by the distribution of individuals among species within the community. The results of this study are consistent with a study conducted in the Supit Urang Waterfall area, Pujon, Malang, which yielded a Shannon-Wiener diversity index value of 3.3 and fell into the moderate category [13]. The similarity in these categories indicates that waterfall areas can provide habitat conditions that support the formation of Pteridophyta communities with moderate levels of diversity. The difference in index values between the two locations indicates that the level of diversity is not only determined by the number of species but can also be influenced by microhabitat conditions, abiotic factors, and the distribution of individual abundance in each area.

The Importance Value Index (IVI) indicates differences in the level of dominance among Pteridophyta species within the community in the study area. The high IVI of *Adiantum tenerum* suggests that this species is relatively better able to utilize microhabitat conditions particularly moisture, light intensity, and substrate characteristics resulting in higher abundance and frequency of occurrence compared to other species. These findings are consistent with studies on the characteristics of waterfall areas, which feature heterogeneous microhabitats due to variations in vegetation cover and environmental conditions. Such studies show that species with high abundance can have high IVI values, such as *Pteris vitata* in the Pepe River watershed [14]. Conversely, the low IVI value of *Pteris vitata* in this study indicates a relatively smaller contribution to community structure, which is presumed to be related to its low abundance and frequency of occurrence. Differences in IVI values among species suggest that each

species has a different ability to utilize microhabitat conditions in the study area.

Characterization of Pteridophyta Spores

The results of the Pteridophyta spore characterization revealed variations in spore aperture type, shape, size, and color. Two types of apertures were identified: trilete in four species and monolete in eight species. The spore shapes observed comprised four types: globose, triangular, elliptical, and kidney shaped. Spore colors also varied, ranging from yellow to dark brown. Spore size was determined based on measurements of the polar axis (PA) and equatorial axis (EA) in micrometers (μm). The polar axis (PA) is the distance between the two poles of the spore, while the equatorial axis (EA) is the diameter of the spore at the equator [15]. Based on size classification, spores are grouped into very small ($<10 \mu\text{m}$), small ($10\text{--}25 \mu\text{m}$), medium ($25\text{--}50 \mu\text{m}$), large ($50\text{--}100 \mu\text{m}$), very large ($100\text{--}200 \mu\text{m}$), and giant ($>200 \mu\text{m}$) [16]. Laboratory observations show that the largest spores were found in *Christella arida*, with a PA of $81 \mu\text{m}$ and an EA of $86 \mu\text{m}$, while the smallest spores were found in *Microlepia speluncae*, with a PA of $31 \mu\text{m}$ and an EA of $23 \mu\text{m}$.

5. CONCLUSION

This study aims to identify the diversity of fern species (Pteridophyta), analyze community structure, and describe spore characteristics in the waterfall area. The results of the study using an exploratory descriptive method showed that the area has environmental conditions that support the growth of Pteridophyta, with 21 species from 8 families and a moderate diversity index ($H' = 2.76$). The *Adiantum tenerum* had the highest dominance level, while *Pteris vitata* had the lowest, indicating differences in adaptation to microhabitats. Spore character variation in terms of shape, size, color, and aperture type, which was dominated by monolete and trilete, confirmed that spore characteristics

are important taxonomic features in supporting the identification and classification of ferns (Pteridophyta).

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