

MAINTAINING ENVIRONMENTAL QUALITY: FIBER CHARACTERIZATION AS A TOOL FOR VERIFYING PULP FIBER COMPOSITION

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ABSTRACT

In an effort to provide a more accurate tool for verifying wood fiber species composing a pulp and paper products, which can affect the properties of the products, a study was conducted to see whether each wood species' fiber has distinctive and significant characteristics that can be used for such verification. The study was initiated by collecting fiber characteristics of wood species grown in Indonesia for making pulp and paper, such as *Acacia mangium*, *Acacia crassicarpa* and *Eucalyptus pelita*, and other alternative wood fiber species, including protected wood species. Each wood species to be examined was processed in three different ways to produce three samples. For the first sample the wood was macerated. For the second sample, instead of maceration, the wood was pulped chemically. For the third sample, the wood was pulped and then refined several times. After processing, each sample was photographed and then its shape, morphology, dimensions and the proportion of its dimensions were examined and recorded. All the data obtained were then stored as a database for verification. The result showed that each wood species has unique fiber characteristics that can be used for identifying its presence in a pulp or paper sheet. For example, comparison between ramin (*Gonystilus bancanus*) fiber and *Acacia mangium* fiber indicated that they differ not only in their dimensions but also in the shape of the fiber, which could be easily recognized. The result also showed that although the pulping and refining processes would cut some of the fibers into two or more sections, the characteristics that were observed in the intact fiber can still be recognized.

Keywords: pulp fiber, fiber identification, *Acacia mangium*, tropical wood, fiber shape

INTRODUCTION

Remarkable development of pulp and paper industries in Indonesia is partly

supported by the relative abundance of wood from its large area of natural tropical forest. Growing awareness on the importance of preserving natural forest,

including its biodiversity, has led the pulp and paper industries to shift their raw material procurement to plantation forest and minimize the utilization of wood from natural forest. The utilization of wood from natural forest in Indonesia excludes several species protected under the national laws because they are in danger of extinction.

Woods used for products such as sawn timber, plywood and furniture are relatively easy to identify since they are still in their basically unaltered (original) form. Identification of wood used for making pulp and paper is more difficult and need a thorough effort (TAPPI, 1992). A study to find a method for identifying wood material composing a pulp and paper product has then been conducted by characterizing the fiber morphology of each wood species.

Characteristics of wood cell could be found in various sources such as Ogata et al. (2008) and Panshin and de Zeeuw (1980) but typically they only provide a general description. This study was directed to find whether each wood has a distinct fiber morphology, and whether it can be used for distinguishing wood fiber of different species. This study was also intended to confirm whether basic wood fiber morphology in a pulp or paper remains unchanged and can be recognized and used for identification.

MATERIALS AND METHODS

Eight different wood species were used in this study. Three of them were pulpwood material commonly used by the pulp and paper industries in Indonesia from plantation forest: *Acacia mangium*, *Acacia crassicarpa* and *Eucalyptus pelita*. Five others are protected wood species

which are most likely to be found in the natural forest of Sumatra, where majority of pulp mills in Indonesia are located. They are ramin (*Gonystylus bancanus*), gaharu (*Aquilaria malaccensis*), jelutung (*Dyera costulata*), kulim (*Scorodocarpus borneensis*) and tembusu (*Fragraea fragrans*). These samples of five wood species were obtained from research forest area in Jambi.

Three different treatments were applied to the wood sample. Wood samples of the first treatment were macerated. As a first step, wood samples of the first treatment were cut into match stick size. The wood samples were then macerated by hydrogen peroxide and glacial acetic acid for 3-4 hours and were followed by staining with safranin for a night. Stained wood fibers were then placed on deck-glass. The wood fibers of each species were photographed by optical light microscope (OLM, Olympus BX 51 DP 72, Japan). The shape, morphology, dimension, proportion of dimension of wood fibers were examined and recorded.

The second treatment was done by pulping all of the eight different species of wood samples and the produced pulps were formed into sheets. The fiber characteristics of the sheets produced were then observed. The third treatment was carried out on selected pulp sheets by beating several times. All the data obtained were then stored as a database for verification. The fiber characteristics of wood samples that have undergone the second and the third treatments were also examined.

RESULTS & DISCUSSION

Fiber characterization studies are directed to determine fiber composition in the pulp or paper sheet using optical light microscope method by conducting a more intensive measurement on fiber dimensions morphology, as an effort to complement TAPPI method, *i.e.* TAPPI T 401 om-88 and TAPPI T 263 om-88.

The study was conducted to observe characteristics of fiber in the pulp or paper sheets under the microscope, by measuring the dimensions and observing the shape of the fiber morphology. The study was focused on observing fiber cell rather than other wood cell element since pulp and paper are mainly composed of fiber cell. (Casey, 1980; Smook, 1994; Biermann, 1996). Data on the types of wood cell found in paper sheet is shown in Table 1.

Table 1 shows that fiber makes up the largest (87.14%) portion of the cells composing the paper sheet, followed by vessel and parenchyma at 6.31 and 6.55%, respectively. From observing cell morphology, a large portion of the fiber was damaged by the beating or refining action during the pulping process which was performed to produce a strong fiber bonding and a good surface smoothness for paper sheet (Casey, 1980; Smook,

1994; Biermann, 1996). Although the vessel and parenchyma do not experience as much damage from the beating and refining process, their quantity is very small in the paper sheet compared to fiber. Therefore, analysis of the fiber composition in the paper sheet will still give more accurate result.

Wood fiber dimensions of the three species *i.e.* *Acacia mangium*, *Acacia crassicarpa* and *Eucalyptus pelita* which are commonly used by pulp and paper industry in Indonesia are shown in Table 2.

Table 2 indicates that among three wood species *A. crassicarpa* has the longest fiber length followed by *A. mangium* and then *E. pelita*. In addition, the cell wall of *A. crassicarpa* is thicker than that of *A. mangium* and *E. pelita*. Morphology of wood fibers of *A. crassicarpa*, *A. mangium* and *E. pelita* are shown in Figure. 1. Fiber characterization was then further observed by measuring the diameter at 11 different points along the the fiber starting from the tip of the fiber up to the middle (center) length at an interval of 5% of fiber length as shown in Figure 2. The measurement at 0% was denoted as the tip of fiber, meanwhile at 50% was the half part of the fiber length. Figure 2 shows the measurement locations which were carried out at 11 points along the half length of fiber in this study.

Table 1. Type of wood cells found in paper sheet

	Fiber	Vessel	Parenchyma	Total
Share in Paper Sheet (%)	87.14	6.31	6.55	100.00
Cell condition :				
Intact (%)	33.52	70.00	60.02	
Damage (%)	66.48	30.00	39.98	

Table 2. Wood fiber dimensions of *Acacia mangium*, *A. crassicarpa* and *Eucalyptus pelita*

	Fiber Diameter (µm)	Lumen Diameter (µm)	Thickness of Cell Wall (µm)	Fiber Length (mm)
<i>A. crassicarpa</i>				
Average	14.400	6.670	3.865	0.985
Minimum	8.254	3.298	1.448	0.708
Maximum	21.275	13.190	7.092	1.326
<i>A. mangium</i>				
Average	15.815	7.998	3.909	0.860
Minimum	8.437	3.773	2.332	0.689
Maximum	20.772	11.761	5.258	1.101
<i>E. pelita</i>				
Average	15.568	8.153	3.707	0.808
Minimum	9.646	4.963	1.476	0.545
Maximum	22.271	12.043	6.535	1.099

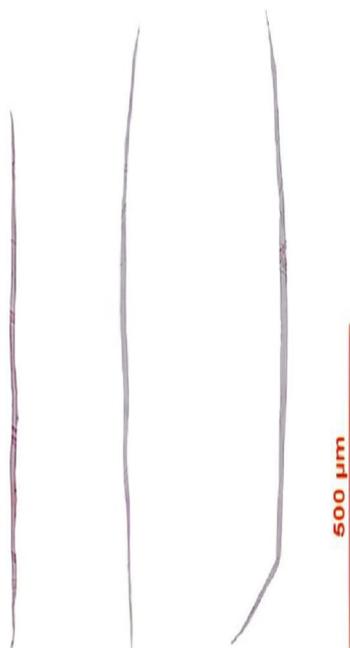


Figure 1. Fibers morphology of *E. pelita*, *A. Mangium*, *A. crassicarpa*

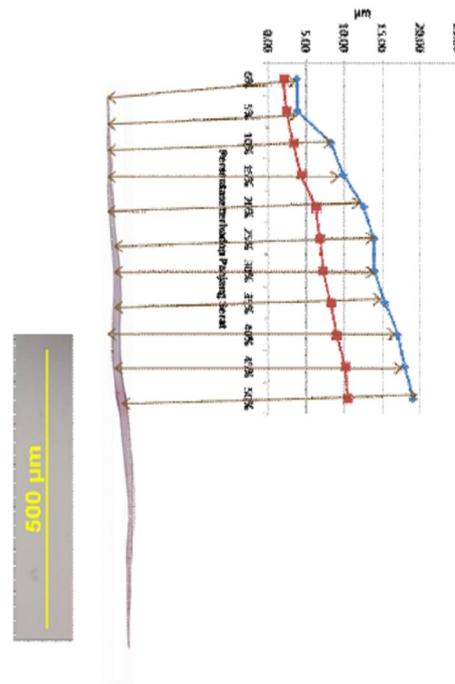


Figure 2. Measurement at 11 points of the half and length of *A. crassicarpa* fiber

Table 3 shows the diameter measured at 11 points up to the half length of wood fiber of *A. mangium*, *A. crassicarpa* and *E. pelita*. The result revealed that the tip area, at around 0 - 15% of the length, of *E. pelita* fiber is thicker than that of *A.*

mangium and *A. crassicarpa*. Meanwhile the dimension measured at 0 – 10% of the length of *A. mangium* fiber tended to be thicker than that of *A. crassicarpa*. Therefore the morphology of fiber tip is

possible to be used as a tool to identify the species especially on these three species.

The ratio of the diameter measured at eleven points along the half length of the wood fiber to the diameter at the half length of wood fiber is shown in Table 4. Those ratios are assumed to be fixed with the variation of fiber length in each species. These ratios emphasized the previous result on the morphology of fiber. The value of the ratios of the tip area at around 0 - 15% of the half length of *E. pelita* fiber is higher than that of *A. mangium* and *A. crassicarpa*. Meanwhile the value of the ratios at the tip area at around 0 - 10% of the half length of *A. mangium* fiber is higher than that of *A. crassicarpa*.

Table 5 shows the fiber dimension of *A. mangium* which were beaten several times. The beaten fibers showed similar

dimension of fiber diameter, lumen diameter and cell wall thickness with the virgin fibers. The beating process did not alter the morphology of *A. mangium* fibers as shown in Fig. 3.

Wood fibers of the three species from plantation forest including *A. crassicarpa*, *A. mangium* and *E. pelita* showed a clear morphological difference with wood fiber of protected species from natural forest such as ramin (*Gonystylus bancanus*), gaharu (*Aquilaria malaccensis*), jelutung (*Dyera costulata*), kulim (*Scorodocarpus borneensis*) and tembusu (*Fragraea fragrans*). Figure 4 shows that the morphology of these species from the shortest fiber to the longest one, respectively. Each wood fiber species, especially from natural forest, exhibits specific characteristics.

Table 3. Fiber diameter measured at eleven points up to the half length of wood fibers

Species	Fiber diameter up to the half length of wood fiber (µm)										
	0%	5%	10%	15%	20%	25%	30%	35%	40%	45%	50%
<i>A. mangium</i>	3.22	5.45	8.62	9.29	10.16	11.03	12.05	13.62	14.60	16.07	17.29
<i>A. crassicarpa</i>	3.76	3.86	8.25	9.85	12.59	13.92	13.94	15.30	17.05	17.96	19.05
<i>E. pelita</i>	7.11	8.79	10.31	10.96	11.62	13.08	14.99	15.31	15.60	16.37	17.59

Table 4. Percentage of the fiber diameter measured at eleven parts along the half length of wood fibers with the dimension at the half of fiber length.

Species	Ratio with the fiber diameter at the half of fiber length										
	0%	5%	10%	15%	20%	25%	30%	35%	40%	45%	50%
<i>A. mangium</i>	0.19	0.32	0.50	0.54	0.59	0.64	0.70	0.79	0.84	0.93	1.00
<i>A. crassicarpa</i>	0.20	0.20	0.43	0.52	0.66	0.73	0.73	0.80	0.89	0.94	1.00
<i>E. pelita</i>	0.40	0.50	0.59	0.62	0.66	0.74	0.85	0.87	0.89	0.93	1.00

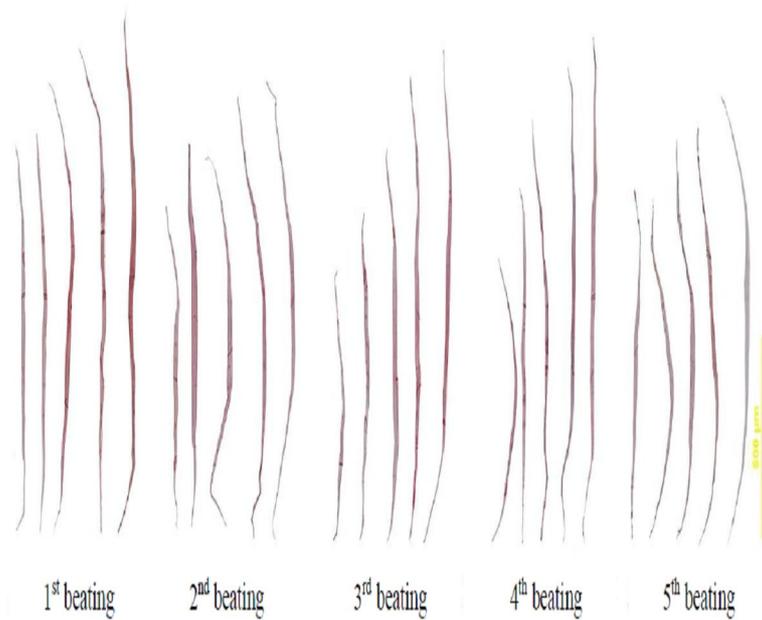


Figure 3. Similarity of morphology of *A. mangium* fibers after several beating process



Figure 4. Morphology of wood fibers of 8 species from plantation and natural forest.

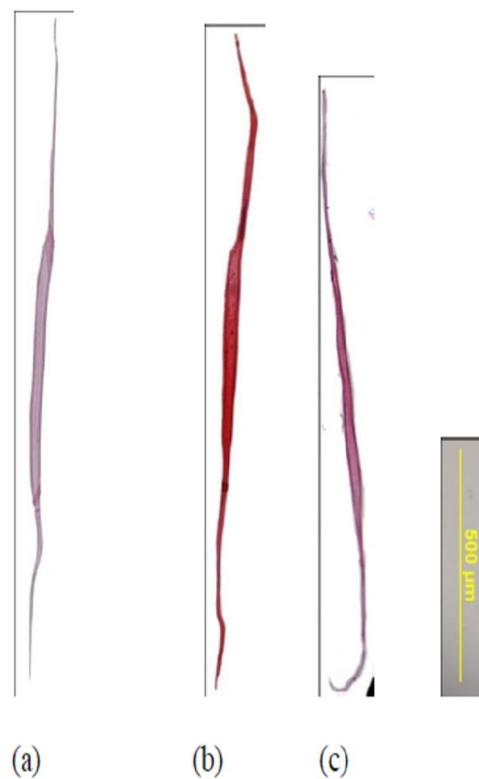


Figure 5. Morphology of (a) virgin fibers, (b) pulped fibers and (c) beaten fibers of ramin

There were two fibers which possess a distinct and thin tail *i.e.* ramin (*Gonystylus bancanus*) and gaharu (*Aquilaria malaccensis*). Ramin has a long tail on both ends of its fiber which is very easy to distinguish from others such as *A. mangium*, *A. crassicarpa* and *E. pelita*, even with gaharu. Although gaharu has fiber tails like ramin, there are significant differences in fiber length and diameter which differentiate it from ramin. The ratio of the tail length and fiber length of ramin and gaharu was 21.8-34.0% and 11.9-14.4%, respectively.

The ratio of tail length and fiber length becomes important on fiber morphology analysis. Jelutung showed a tapered and asymmetrical fiber tips, with the fiber length, diameter and cell wall thickness of 1.4 mm, 55.94 μm and 16.19 μm , respectively. Kulim has a relatively long fiber compared to other broad leaf fibers of 2,210.32 μm . This fiber shows a rather special characteristic because the size of the fiber is close to conifer, like such as *Pinus merkusii*. However kulim possessed a specific characteristic of the fiber *i.e.* a large ratio of length to diameter (slender). Morphology of ramin fiber is also unaltered after pulping and beating process as shown in Fig. 5.

Measurements of fiber morphology above are divided into a few parameters *i.e.* fiber length, fiber dimension of tip, fiber dimension of middle, fiber dimension, lumen diameter, cell wall thickness, length of tail, length of body, Runkel ratio, Muhlstep ratio, felting power, coefficient of rigidity and flexibility ratio. Measurements were made with more detail, following the special shape or clue of the fiber morphology. Dimensional measurement data and fiber morphology are shown in the Table 6 and 7. Figure 6 illustrate the dimensional measurements, especially for fibers with a tail section.

The Table 6 and 7 shows *A. mangium*, and *Gonystylus bancanus* were measured at different classes of fiber length to show fiber form in detail. Measurement of the dimensions and morphology *A. mangium* carried on fiber length 700-1000 μm and 700-1100 μm , according to the range of variation found in this species, while *Gonystylus bancanus*, measurements were made on fiber length 900-1700 μm , much longer. Measurements at different fiber length will cause the size of the dimensions, morphology and derivatives of different fiber dimensions.

Table 5. Fiber dimension of *A. mangium* at some level beating

Parameters	Number of beating				
	1 st	2 nd	3 rd	4 th	5 th
Fiber diameter (μm)	18.39	18.06	19.09	19.48	19.43
Lumen diameter (μm)	6.662	4.709	7.032	6.629	6.792
Cell Thick Wall (μm)	5.864	6.674	6.030	6.426	6.321
Fiber Length (mm)	950.7	970.2	961.3	980.0	958.8

Table 6. Fiber dimension and morphology of *A. mangium* at various fiber length

<i>A. mangium</i>	Parameter	Class of Fiber length (μm)				
		700	800	900	1000	1100
Dimension	FL (μm)	714	792.72	900.44	990.13	1143.43
	FDT (μm)	NA	NA	NA	NA	NA
	FDM (μm)	NA	NA	NA	NA	NA
	FD (μm)	12.71	13.27	11.19	16.49	13.99
	LD (μm)	5.81	6.58	4.38	9.83	6.46
	CWT (μm)	3.45	3.34	3.40	3.33	3.76
Morphology	FTL (μm)	NA	NA	NA	NA	NA
	BL (μm)	NA	NA	NA	NA	NA
	FTL:BL	NA	NA	NA	NA	NA
	FTL: FL	NA	NA	NA	NA	NA
Derived values	RR	1.19	1.02	1.56	0.68	1.17
	MR	79.12	75.39	84.69	64.48	78.68
	FP	56.20	59.72	80.50	60.04	81.76
	CR	0.27	0.25	0.30	0.20	0.27
	FR	0.46	0.50	0.39	0.60	0.46

Note : FL = Fiber Length; FDT = Fiber Diameter of Tail stem; FDM = Fiber Diameter of Middle of fiber; FD = average Fiber Diameter; LD = Lumen Diameter; CWT = Cell Wall Thickness; FTL = Tail Length; BL = Body Length (FL – 2 x FTL); RR = Runkel Ratio; MR = Muhstep Ratio; FP = Felting Power; CR = Coefficient of Rigidity; FR = Flexibility Ratio; NA = Not Applicable.

Table 7. Fiber dimension and morphology of *Gonystylus bancanus* at various fiber length

<i>Gonystylus bancanus</i>	Parameter	Class of Fiber length (μm)								
		900	1000	1100	1200	1300	1400	1500	1600	1700
Dimension	FL (μm)	995.37	1079.06	1186.48	1272.92	1373.49	1413.07	1521.25	1643.84	1734.30
	FDT (μm)	18.11	16.46	23.87	25.04	20.09	23.39	21.28	27.41	23.21
	FDM (μm)	17.67	23.37	28.19	27.51	23.90	27.57	22.85	28.82	30.84
	FD (μm)	17.89	19.91	26.03	26.27	22.00	25.48	22.06	28.12	27.03
	LD (μm)	4.51	4.99	4.61	8.85	3.64	6.82	4.58	7.31	5.64
	CWT (μm)	6.69	7.46	10.71	8.71	9.18	9.33	8.74	10.40	10.69
Morphology	FTL (μm)	272.43	263.42	403.05	277.19	405.72	422.79	507.28	447.51	473.40
	BL (μm)	450.51	552.22	380.38	718.53	562.06	567.49	506.69	748.83	787.50
	FTL:BL	60.47	47.70	105.96	38.58	72.18	74.50	100.12	59.76	60.11
	FTL: FL	27.37	24.41	33.97	21.78	29.54	29.92	33.35	27.22	27.30
Derived Values	RR	2.96	2.99	4.65	1.97	5.04	2.74	3.82	2.85	3.79
	MR	93.64	93.71	96.87	88.64	97.26	92.84	95.69	93.25	95.65
	FP	55.64	54.19	45.58	48.45	62.44	55.45	68.95	58.47	64.17
	CR	0.37	0.37	0.41	0.33	0.42	0.37	0.40	0.37	0.40
	FR	0.25	0.25	0.18	0.34	0.17	0.27	0.21	0.26	0.21

Note : same as Table 6.

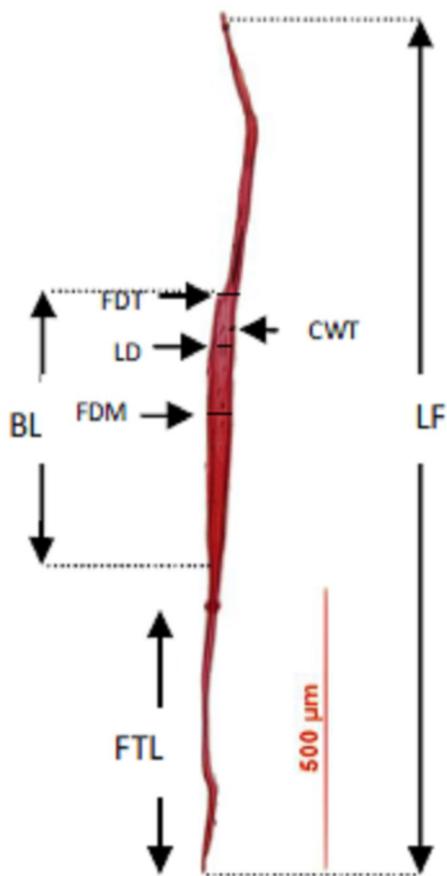


Figure 6. Dimension and morphology measurement illustration

Fiber characterization method can determine the fiber composition of paper sheet based on the results of the qualitative and quantitative analysis. Qualitative analysis of the fiber can be carried out by observing the fiber's morphological characteristics and dimensions. The accuracy of the method is dependent on the comprehensiveness of the database of fiber dimension and morphology on various species, which should include specific characteristics or markers. Quantitative results can be obtained by grouping together fibers which were observed under the microscope to

have with the same characteristics and markers. The quantity of the fibers in the groups were then calculated and expressed as a percentage of the total.

The result of this study is useful for the pulp and paper industry on the legal aspects of the raw materials used. This method will verify the fiber composition and fiber of the alleged use of endangered species in the product.

CONCLUSIONS

Fiber composes the largest part of wood cells in finished paper product at around 87%, compared to other cells such as vessel and parenchyma at around 6%-7% for each. Furthermore, vessels are only found in hardwood species and not in softwood species. Therefore, analysis of wood fiber in paper products will provide a more accurate assessment of fiber composition by species.

Every fiber sample has unique characteristics in its morphology and comparison of the fiber dimensions and its ratios can be used to determine fiber species. The following dimensional and morphological parameters can be further developed into a tool set to determine fiber species: FL = Fiber Length; FDT = Fiber Diameter of Tip; FDM = Fiber Diameter of Middle; FD = Fiber Diameter; LD = Lumen Diameter; CWT = Cell Wall Thickness; FTL = Fiber Tail length; FBL = Fiber Body Length; Ratio FTL and FBL; Ratio FTL and FL RR = Runkel Ratio; MR = Muhlstep Ratio; FP = Felting Power; CR = Coefficient of Rigidity; FR = Flexibility Ratio. To ensure that the tool set can be used by the industry, a comprehensive library or database for the parameters for the

various species is required. Experiments indicate that the pulping and beating process does not significantly alter the basic morphology of the fiber which characterizes it.

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