Brief Dataset on produced handsheet from oil palm residue lignocellulose treated with *Bacillus cereus* on mechanical and physical characterization

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This article presents experimental data on oil palm biomass (oil palm leaves, oil palm trunk and empty fruit bunch) handsheet production characterization by biodelignification treatment using *Bacillus cereus* extracted from termite gut (*Coptotermes curvignathus*). It associates the lignocellulose chemical composition obtained via technical association pulp and paper industry TAPPI T 222 om-02 testing on lignin content reduction determination, holocellulose and hemicellulose content determination (Kurscher-Hoffner method). Several data obtained for handsheet characterization presents brightness, opacity, contrast ratio, din transparency, thickness, bursting and tearing indexes are collected. Handsheet surface morphology was also observed on ratio of gaps differences between fiber bonding conducted using scanning electron microscope (SEM) and ImageJ software. The raw data findings supplement chemical composition analysis for both untreated and treated substrates on handsheet quality performance check as presented in the research article “Bio-Mechanical Pulping of Bacteria Pre-Treatment on Oil Palm...”

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Biomass for Handsheet Production” [1]. For understanding correlations into the difference among lignocellulose content composition which affect the handsheet formation and mechanical strength refer to article from this research [1]. This dataset is made publicly available for optimizing alternative waste material reuse in the pulp and paper industrial section. © 2021 The Authors. Published by Elsevier Inc. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/)

### Specifications Table

| Subject | Material Science |
|---------|------------------|
| Specific subject area | Oil palm lignocellulose content on reusable biomass waste for paper production |
| Type of data | Lignocellulose compositions were recorded using an analytical balance (AUX120, SHIMADZU, Co., Japan). The mechanical tests conducted are, thickness of sheet using a micrometre (Lorentzen & Weltr, Sweden) (TAPPI Standard T 411 om-10), grammage (TAPPI Standard T220 sp-01), tensile index analysed using horizontal tensile tester (BUCHEL, Netherlands) (TAPPI Standard T404 cm-02), tear strength using tearing resistance tester (Lorentzen & Weltr, Sweden) (TAPPI Standard T414 om-98) and bursting of pulp using the bursting tester (FRANK Prüfgerate GmbH, Austria) (TAPPI Standard T 403 om-08). Scanning Electron Microscopy (SEM) micrographs captured using number series SU1510 (FUSIO Hitachi, Japan) coated with thin layer of gold using a sputter-coated (Quorum Q150R S, UK). Raw data, statistical analysis (Microsoft excel, ANOVA), and images (Samsung J7pro. Korea). |
| How data were acquired | Tables and images |
| Data format | Oil palm residue: oil palm leaf (OPL), oil palm trunk (OPT) and empty fruit bunch (EFB) were treated for biopulp at pH of 6.5 at 37 °C, 120 rpm and 7 days via submerged fermentation. Subsequently, specimens were autoclaved, washed and dried before handsheet making. Thereafter, the handsheets samples were subjected to chemical composition, surface morphology analysis and mechanical properties characterization. |
| Parameters for data collection | Lignocellulose chemical composition was determined based on TAPPI T 222 om-66, Chlorite method, and Kurscher-Hoffner method [6]. The mechanical and physical properties were recorded and evaluated according to TAPPI T 220 sp-01, the physical testing of pulp [1,7], Surface morphology of handsheets was observed using scanning electron microscope (SEM) and imagej software analysis [12]. Statistical analysis determined using ANOVA for standard deviation and analyzed. |
| Description of data collection | Institution: Universiti Tun Hussein Onn Malaysia City/Town/Region: Panchor, Pagoh, Johor Country: Malaysia AND Institution: Forest Research Institute Malaysia (FRIM) City/Town/Region: Bukit Kepong, Selangor Country: Malaysia |
| Data source location | The data is available at Mendeley Data. Data Repository: http://dx.doi.org/10.17632/yfrs3rbzwf.1 |
| Data accessibility | Sharifina Mutia Syarifah, Anggazas Sari Mohd Kassim, Ashuvila Mohd Aripin, Nadiah Ishak, Ayeronfe Fadilat, Sharmiza Adnan Bio-Mechanical Pulping of Bacteria Pre-Treatment on Oil Palm Biomass for Handsheet Production 10.14419/ijet.v8i1.1.24657 |
| Related research article | • The data are useful characterization for optimization and determining better paper quality for bacteria treatment biopulp on oil palm residues and variety plant sources. |

**Value of the Data**

- The data are useful characterization for optimization and determining better paper quality for bacteria treatment biopulp on oil palm residues and variety plant sources.
• The data helps oil palm substrates lignocellulose content comparison and validation with related potential lignocellulose substrate from other various plant sources.
• These data benefit other researchers to utilize oil palm residues as alternative source for environmentally friendly materials.

1. Data Description

The oil palm residue: oil palm leaf (OPL), oil palm trunk (OPT) and empty fruit bunch (EFB) lignocellulose chemical composition are determined and summarized in Table 1. The values determined the delignification percentage and the effect of bacterial treatment on lignocellulose composition as different substrates shown different reaction towards bacterial delignification. In Table 2, the ANOVA analysis on lignocellulose delignification shows significant results (p < 0.05) as to support the chemical composition result. In Table 3, some potential lignin degraders are compared as this shows more potential of Bacillus cereus degradation with further optimization. The produced handsheet was recorded in TAPPI standard testing data on mechanical and physical properties as shown in Tables 4, 5 and 6. Tensile index is the most important mechanical testing to evaluate the strength level of a handsheet material as this was recorded in Table 4. In Tables 5 and 6, the data on tearing and bursting indexes, were recorded respectively as this also contributes towards handsheet rupture characteristics. The handsheet thickness is important.

Table 1
Lignocellulose chemical composition of oil palm residues material on raw and treated samples.

| Chemical Composition (%) | Untreated OPL ± standard error | Treated OPL ± standard error | Untreated OPT ± standard error | Treated OPT ± standard error | Untreated EFB ± standard error | Treated EFB ± standard error |
|--------------------------|-------------------------------|-------------------------------|-------------------------------|-------------------------------|-------------------------------|-------------------------------|
| Lignin                   | 27.1 ± 0.17                  | 25.2 ± 0.17                  | 21.3 ± 0.08                  | 19.3 ± 0.26                  | 22.2 ± 0.12                  | 17.4 ± 0.22                  |
| Holocellulose            | 77.9 ± 0.24                  | 76.5 ± 0.39                  | 70.9 ± 0.18                  | 71.9 ± 0.46                  | 79.3 ± 0.22                  | 73.7 ± 0.26                  |
| Hemicellulose            | 33.9 ± 0.21                  | 32.7 ± 0.16                  | 30.0 ± 0.18                  | 30.9 ± 0.54                  | 33.4 ± 0.22                  | 31.4 ± 0.41                  |
| Cellulose                | 44.0 ± 0.39                  | 43.8 ± 0.36                  | 40.9 ± 0.52                  | 41.0 ± 0.06                  | 45.9 ± 0.10                  | 42.3 ± 0.37                  |

*standard error or standard deviation of samples.

Table 2
One-Way ANOVA analysis on lignocellulose chemical compositions of OPL, OPT and EFB.

| Source of Variation | SS         | df | MS          | F            | P-value | F crit     |
|---------------------|------------|----|-------------|--------------|---------|------------|
| Lignin analysis     |            |    |             |              |         |            |
| Between Groups      | 195.3138272 | 5  | 39.0627654  | 881.3604457  | 5.86094E-15 | 3.105875  |
| Within Groups       | 0.531851852 | 12 | 0.044320988 |              |         |            |
| Total               | 195.845679  | 17 |             |              |         |            |
| Holocellulose analysis |          |    |             |              |         |            |
| Between Groups      | 231.1058333 | 5  | 46.22116667 | 368.5408638  | 1.80629E-17 | 2.772853  |
| Within Groups       | 2.2575     | 18 | 0.12541667  |              |         |            |
| Total               | 233.3633333 | 23 |             |              |         |            |
| Hemicellulose analysis |          |    |             |              |         |            |
| Between Groups      | 34.15422885 | 5  | 6.830845771 | 44.36880561  | 2.50299E-07 | 3.105875  |
| Within Groups       | 1.847472523 | 12 | 0.153956044 |              |         |            |
| Total               | 36.00170138 | 17 |             |              |         |            |
| Cellulose analysis  |            |    |             |              |         |            |
| Between Groups      | 56.80708028 | 5  | 11.36141606 | 31.38093534  | 1.71612E-06 | 3.105875  |
| Within Groups       | 4.344580274 | 12 | 0.362048356 |              |         |            |
| Total               | 61.15166056 | 17 |             |              |         |            |
as this might contribute towards the strength of handsheet and formation which the recorded values are listed in Table 7. Respectively in Tables 8, 9 and 10 shows readings for brightness, ISO opacity or printing contrast, opacity ($R_D$) and infinity reflectance ($R_{\infty}$) for both untreated and treated samples of OPL, OPT and EFB, respectively. The ability of handsheet fiber to have brighter surface color and the reflectance and absorbance of light may affect paper production type and reduces bleaching processes. Higher opacity is expected for clearer handsheet image view and printing properties. The fiber bonding of handsheets produced observed by scanning electron microscope (SEM) and ImageJ software analysis has determined the area gaps as given in Tables 12 and 13 for both 50x and 200x magnification, respectively, and the summarized data are shown in Table 11. Good bonding resulted compact view with smaller gap structure and the cellulose fibers are more visible. Physical strength of handsheet are observed through SEM micrographs captured at 50x and 200x magnifications are shown in Fig. 1. Photographs of handsheet produced from oil palm residues in the experiment for both untreated and treated samples: oil palm leaf (OPL), oil palm trunk (OPT) and empty fruit bunch (EFB) are shown in Fig. 2. The explained results and discussion can be read in the referred research paper for the mechanical and physical [1].

- In Table 1, the OPT result showed an increase of holocellulose, hemicellulose and cellulose component due to enzymatic effect on preserving bond chains [2].
- The lignin degradation decreased 7% to 21.7% only by using bacteria treatment in 7 days.

SEM data are useful to predict fiber bonding structures and to determine strength capability in plant fibres.
Table 5
Recorded data on tearing index of oil palm residue samples.

| Untreated OPL Index (mN.m²/g) | Treated OPL Index (mN.m²/g) | Untreated OPT Index (mN.m²/g) | Treated OPT Index (mN.m²/g) | Untreated EFB Index (mN.m²/g) | Treated EFB Index (mN.m²/g) |
|-------------------------------|-------------------------------|-------------------------------|-------------------------------|-------------------------------|-------------------------------|
| n.a                           | 0.427                         | 0.705                         | 1.026                         | 1.212                         | 1.634                         |
| n.a                           | 0.513                         | 0.705                         | 0.746                         | 1.212                         | 1.736                         |
| n.a                           | 0.427                         | 0.617                         | 0.933                         | 1.111                         | 1.736                         |
| n.a                           | 0.342                         | 0.617                         | 0.839                         | 1.212                         | 1.634                         |

| Mean stdv                     | Mean stdv                     | Mean stdv                     | Mean stdv                     | Mean stdv                     | Mean stdv                     |
| n.a                          | n.a                           | 0.427                         | 0.061                         | 0.661                         | 0.044                         | 0.886                         | 0.048                         | 1.186                         | 0.051                         | 1.685                         |
### Table 6
Recorded data on bursting index of oil palm residue samples.

| Untreated OPL Index (kPa.m² /g) | Treated OPL Index (kPa.m² /g) | Untreated OPT Index (kPa.m² /g) | Treated OPT Index (kPa.m² /g) | Untreated EFB Index (kPa.m² /g) | Treated EFB Index (kPa.m² /g) |
|-------------------------------|-------------------------------|-------------------------------|-------------------------------|-------------------------------|-------------------------------|
| n.a                           | 0.087                         | 0.148                         | 0.235                         | 0.187                         | 0.343                         |
| n.a                           | 0.121                         | 0.091                         | 0.235                         | 0.186                         | 0.351                         |
| n.a                           | 0.088                         | 0.077                         | 0.224                         | 0.137                         | 0.335                         |
| n.a                           | 0.088                         | 0.077                         | 0.184                         | 0.130                         | 0.331                         |
| n.a                           | 0.090                         | 0.112                         | 0.175                         | 0.130                         | 0.376                         |
| n.a                           | 0.065                         | 0.105                         | 0.226                         | 0.145                         | 0.374                         |
| n.a                           | 0.070                         | 0.110                         | 0.194                         | 0.130                         | 0.362                         |
| n.a                           | 0.062                         | 0.077                         | 0.190                         | 0.125                         | 0.294                         |

| Mean                          | n.a                           | Mean                          | 0.084                         | Mean                          | 0.100                         | Mean                          | 0.208                         | Mean                          | 0.146                         | Mean                          | 0.346                         |
| Stdv                          | n.a                           | Stdv                          | 0.018                         | Stdv                          | 0.023                         | Stdv                          | 0.023                         | Stdv                          | 0.024                         | Stdv                          | 0.025                         |
Table 7
Recorded data on thickness reading of oil palm residue samples.

| No. | Sample | Untreated OPL | Treated OPL | Untreated OPT | Treated OPT | Untreated EFB | Treated EFB |
|-----|--------|---------------|-------------|--------------|-------------|---------------|-------------|
|     |        | Thickness (μm) |             |              |             |               |             |
| 1   |        | 681.0         | 806.5       | 760.6        | 879.8       | 727.8         | 633.3       |
| 2   |        | 705.2         | 806.2       | 784.1        | 914.3       | 699.1         | 637.3       |
| 3   |        | 701.4         | 803.1       | 791.4        | 905.6       | 739.1         | 617.4       |
| 4   |        | 667.7         | 818.2       | 787.8        | 889.0       | 711.7         | 625.9       |
| 5   |        | 680.4         | 860.9       | 807.1        | 901.4       | 752.9         | 637.0       |
| 6   |        | 716.2         | 812.1       | 762.4        | 869.9       | 708.6         | 640.4       |
| 7   |        | 743.9         | 795.0       | 758.6        | 871.1       | 697.4         | 654.3       |
| 8   |        | 705.2         | 794.1       | 751.5        | 903.6       | 741.0         | 628.1       |
| 9   |        | 696.1         | 789.9       | 733.8        | 863.6       | 697.5         | 633.8       |
| 10  |        | 674.7         | 852.4       | 767.8        | 895.7       | 702.3         | 665.3       |

| Mean |        | 697.2         | 813.8       | 770.5        | 889.4       | 717.7         | 837.3       |
| Stdv |        | 22.6          | 24.2        | 21.8         | 17.5        | 20.7          | 13.8        |
| CoV (%) |      | 3.24          | 2.97        | 2.83         | 1.97        | 2.88          | 2.17        |
| Max. |        | 743.9         | 860.9       | 807.1        | 914.3       | 752.9         | 665.3       |
| Min. |        | 667.7         | 789.9       | 733.8        | 863.6       | 697.4         | 617.4       |

Table 8
Brightness and opacity readings of oil palm leaf (OPL) handsheet samples.

| No. | Sample | Untreated OPL | Treated OPL |
|-----|--------|---------------|-------------|
|     |        | Brightness (%) | ISO Opacity (%) | R₀ | R∞ | Brightness (%) | ISO Opacity (%) | R₀ | R∞ |
| 1   |        | 12.45         | 99.01        | 21.07 | 21.28 | 13.29         | 100.17        | 22.93 | 22.89 |
| 2   |        | 12.56         | 99.12        | 21.22 | 21.41 | 13.24         | 99.31         | 22.59 | 22.74 |
| 3   |        | 12.19         | 98.61        | 20.67 | 20.96 | 13.43         | 99.43         | 22.94 | 23.07 |
| 4   |        | 12.15         | 98.61        | 21.33 | 21.63 | 13.03         | 98.65         | 22.52 | 22.82 |
| 5   |        | 12.72         | 99.24        | 22.22 | 22.39 | 13.35         | 99.89         | 22.69 | 22.71 |
| 6   |        | 12.39         | 99.19        | 21.08 | 21.25 | 13.35         | 99.40         | 22.58 | 22.72 |
| 7   |        | 11.98         | 99.82        | 20.76 | 20.79 | 13.61         | 99.42         | 22.55 | 22.68 |
| 8   |        | 12.47         | 98.51        | 21.25 | 21.57 | 13.37         | 99.33         | 22.61 | 22.76 |

| AVG |        | 12.37         | 99.01        | 21.20 | 21.41 | 13.33         | 99.45         | 22.68 | 22.80 |
| STDV |      | 0.243          | 0.435        | 0.472 | 0.486 | 0.165          | 0.444         | 0.167 | 0.128 |

2. Experimental Design, Materials and Methods

2.1. Materials

Oil palm biomass (oil palm leaf, oil palm trunk and empty fruit bunch) fibers were obtained from the plantation area in Parit Daun, Parit Raja, Johor, Malaysia. Oil palm waste fibers were thoroughly washed with tap water then dried in a universal oven (Memmert, Germany) to a constant moisture (10%) at 50 °C overnight [7].

2.2. Biopulp preparation

The bacteria used in this experiment were retrieved from Dr. Patricia Hung at Universiti Putra Malaysia, Bintulu Sarawak in a form of collaboration work. The selected *Bacillus cereus* was used for the biodelignification with the use of sample substrates as their sole carbon source. Bacteria preparations were conducted in biosafety cabinet (ESCO Airstream®, Singapore). The biopulps were prepared via submerged fermentation (SmF) [8]. The cultivation condition of SmF was adjusted to pH of 6.5 at 37 °C, 120 rpm and 7 days in an incubator shaker (DaihanSci, Korea) [9]. After 7 days of cultivation, the biopulps were autoclaved (Tomy Autoclave SX 500, Japan),
### Table 9
Brightness and opacity readings of oil palm trunk (OPT) handsheet samples.

| No. Sample | Brightness (%) | ISO Opacity (%) | $R_0$ | $R_\infty$ | Brightness (%) | ISO Opacity (%) | $R_0$ | $R_\infty$ |
|------------|----------------|-----------------|------|------------|----------------|-----------------|------|------------|
| 1          | 22.46          | 99.15           | 34.83| 35.13      | 20.40          | 99.21           | 31.55| 31.80      |
| 2          | 22.28          | 99.78           | 34.83| 34.91      | 20.14          | 99.57           | 31.63| 31.77      |
| 3          | 22.77          | 98.76           | 34.88| 35.32      | 20.30          | 99.21           | 31.10| 31.35      |
| 4          | 22.48          | 99.34           | 34.97| 35.21      | 20.27          | 99.08           | 30.93| 31.22      |
| 5          | 22.83          | 99.40           | 35.05| 35.26      | 20.02          | 100.16          | 31.10| 31.05      |
| 6          | 22.56          | 99.44           | 35.03| 35.23      | 20.11          | 99.47           | 31.13| 31.30      |
| 7          | 22.38          | 99.29           | 34.82| 35.06      | 20.17          | 99.39           | 31.12| 31.31      |
| 8          | 22.76          | 99.14           | 35.14| 35.45      | 20.12          | 98.51           | 31.00| 31.47      |

| AVG        | 22.57          | 99.29           | 34.94| 35.20      | 20.19          | 99.32           | 31.2 | 31.41      |
| STDV       | 0.201          | 0.292           | 0.123| 0.164      | 0.123          | 0.467           | 0.254| 0.262      |

### Table 10
Brightness and opacity readings of empty fruit bunch (EFB) handsheet samples.

| No. Sample | Brightness (%) | ISO Opacity (%) | $R_0$ | $R_\infty$ | Brightness (%) | ISO Opacity (%) | $R_0$ | $R_\infty$ |
|------------|----------------|-----------------|------|------------|----------------|-----------------|------|------------|
| 1          | 39.58          | 96.59           | 52.64| 54.50      | 33.45          | 98.45           | 48.35| 49.10      |
| 2          | 40.40          | 96.89           | 53.56| 55.27      | 33.50          | 98.53           | 48.48| 49.20      |
| 3          | 39.63          | 97.55           | 53.47| 54.81      | 33.15          | 99.31           | 48.47| 48.81      |
| 4          | 40.30          | 97.33           | 54.07| 55.55      | 33.20          | 98.74           | 48.33| 48.95      |
| 5          | 40.10          | 97.40           | 54.01| 55.46      | 33.20          | 98.51           | 48.25| 48.98      |
| 6          | 40.24          | 97.17           | 53.83| 55.40      | 33.21          | 99.10           | 48.54| 48.98      |
| 7          | 40.49          | 96.12           | 53.47| 55.63      | 33.26          | 99.08           | 48.71| 49.16      |
| 8          | 39.50          | 97.32           | 53.38| 54.85      | 32.87          | 98.67           | 48.09| 48.73      |

| AVG        | 39.98          | 97.05           | 53.55| 55.18      | 33.23          | 98.80           | 48.40| 48.99      |
| STDV       | 0.371          | 0.484           | 0.452| 0.411      | 0.193          | 0.317           | 0.190| 0.162      |

### Table 11
Summary of handsheet fiber bonding gaps area on SEM analysis.

| Magnification (mm²) | Untreated OPT | Treated OPT | Untreated OPT | Treated OPT | Untreated EFB | Treated EFB |
|--------------------|---------------|-------------|---------------|-------------|---------------|-------------|
| 50x                | 1.72 ± 0.12*  | 1.22 ± 0.67* | 0.71 ± 0.29*  | 0.36 ± 0.24* | 0.91 ± 0.05*  |             |
| 200x               | 1.04 ± 0.68*  | 0.54 ± 0.28* | 0.15 ± 0.09*  | 0.05 ± 0.02* | 0.13 ± 0.09*  | 0.03 ± 0.01* |

*standard error or standard deviation.

### Table 12
Area gaps of fiber bonding on handsheet SEM micrographs analysis at 50x magnification.

| No. Sample | Untreated OPT | Treated OPT | Untreated OPT | Treated OPT | Untreated EFB | Treated EFB |
|------------|---------------|-------------|---------------|-------------|---------------|-------------|
| 1          | 0.975         | 1.916       | 0.861         | 0.428       | 0.207         | 0.051       |
| 2          | 0.792         | 0.907       | 1.098         | 0.268       | 0.840         | 0.114       |
| 3          | 2.449         | 0.701       | 0.635         | 0.171       | 0.872         | 0.118       |
| 4          | 3.150         | 0.572       | 0.231         | 0.402       | 0.249         | 0.214       |
| 5          | 1.033         | 0.406       | 0.544         | 0.911       | 0.221         | 0.092       |
| 6          | 2.518         | 0.787       | 0.989         | 0.620       | 0.840         | 0.093       |
| 7          | 3.910         | 2.242       | 0.448         | 0.156       | 0.767         | 0.158       |
| 8          | 0.878         | 1.101       | 1.072         | 0.199       | 0.303         | 0.096       |
| 9          | 0.935         | 2.333       | 0.383         | 0.355       | 0.263         | 0.122       |
| 10         | 0.565         | 1.236       | 0.845         | 0.080       | 0.335         | 0.037       |

| Average    | 1.721         | 1.220       | 0.711         | 0.359       | 0.490         | 0.110       |
| STDV       | 1.121         | 0.665       | 0.290         | 0.238       | 0.281         | 0.048       |
| Min.       | 0.565         | 0.406       | 0.231         | 0.156       | 0.207         | 0.051       |
| Max.       | 3.910         | 2.333       | 1.098         | 0.911       | 0.872         | 0.214       |
cleaned and dried for handsheet making. The handsheets were prepared at Forest Research Institute Malaysia (FRIM) as according to the standard TAPPI T 205 sp-02 [10]. Handsheets were made at a laboratory scaled basis, which consisted of 12 sets of paper made in accordance with 60 g per meter square (gsm).

2.3. Lignocellulose chemical composition

The samples prepared were Soxhlet (MTOPs, Korea) for 6 h using acetone (C₃H₆O) as the solvent extraction at 90 °C according to TAPPI T264 om-88 Standard Process. Several standard approaches were used to evaluate lignin (TAPPI T 222 om-66), holocellulose and hemicellulose (Chlorite method), and Cellulose (Kurscher-Hoffner method) [11]. Lignocellulose composition contents were recorded using an analytical balance (AUX120, SHIMADZU, Co., Japan).

2.4. Mechanical properties tests

Mechanical properties tests were conducted to evaluate the handsheet physical form in order to determine quality and strength of the handsheets for paper production. Mechanical properties testing was performed according to standard TAPPI T 220 sp-01, the physical testing of pulp [12]. All the tests were performed inside an acquired strict condition in a dedicated room used for the drying of handsheets standardized TAPPI T 402 sp-03 [13]. The mechanical tests selected in this study were, thickness of sheet using a micrometer (Lorentzen & Weltre, Sweden) (TAPPI Standard T 411 om-10), grammage (TAPPI Standard T220 sp-01), tensile index analysed using horizontal tensile tester (BUCHEL, Netherlands) (TAPPI Standard T404 cm-02), tear strength using tearing resistance tester (Lorentzen & Weltre, Sweden) (TAPPI Standard T414 om-98) and bursting of pulp using the bursting tester (FRANK Prufgerate GmbH, Austria) (TAPPI Standard T 403 om-08). The preparation of testing sheets was cut into designed shapes that fit the testing apparatus of each machine as shown in Fig 3.

2.5. Brightness and opacity tests

The optical quality of the handsheet was tested on the opacity and brightness according to (TAPPI Standard T425 om-01) and (TAPPI Standard T 452 om-02) respectively. In this procedure,
Fig. 1. SEM micrographs of oil palm handsheet showing fiber bonding distributions and orientation of each sample (a) untreated OPL, (b) untreated OPT, (c) untreated EFB, (d) treated OPL, (e) treated OPT, and (f) treated EFB captured at 50x (above picture) and 200x (below picture) magnifications respectively.

an opacimeter (Color Touch Technidyne, USA) was used for the testing process. The specimen sample standard was placed at the opacimeter and adjusted for the instrumentation reading for absolute reflectance calibration.

2.6. Scanning electron microscope (SEM) analysis

Handsheet samples were cut into different small pieces of about 1 cm were then subjected to gold coating using sputter-coated (Quorum Q150R S, UK). The surface morphology analysis used scanning electron microscope (SEM) number series SU1510 (FUSIO Hitachi, Japan). To begin, the chamber was vented from the first tab for approximately 90 s. The sample was placed on the sample holder using a clipper. The coated residues were placed on to the sample holder and adjusted to about 13–25 mm distance (i.e., the distance between the bottom of the SEM column and specimens’ top). The sample was put into the SEM chamber for analysis and was operated
Fig. 2. Photographs of produced oil palm residue handsheet (a) untreated OPL, (b) treated OPL, (c) untreated OPT, (d) treated OPT, (e) untreated EFB, and (f) treated EFB are modified from Syarifah et al. [1].

Fig. 3. Paper cut portions for physical testing.

at 15 kV [14]. The surface morphology was visualized at 50× and 200× magnification. Area gaps seen between the fiber bonding on the images were analysed using imageJ software for statistical analysis.
2.7. Statistical analysis

All of the statistical analyses were attested for mean ± standard error of the mean (SEM) or standard deviation. The chemical composition analysis was tested for significant difference using ANOVA in Microsoft Excel software. The p-values of less than 0.05 were taken as significant ($p < 0.05$).

Declaration of Competing Interest

The authors declare that they have no conflicting financial interests or personal enterprises that may affect or influence the reported work in this paper.

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