# Steam Pretreatment Enhancing Productivity of Cellulose Nanofibrils from Oil Palm Biomass

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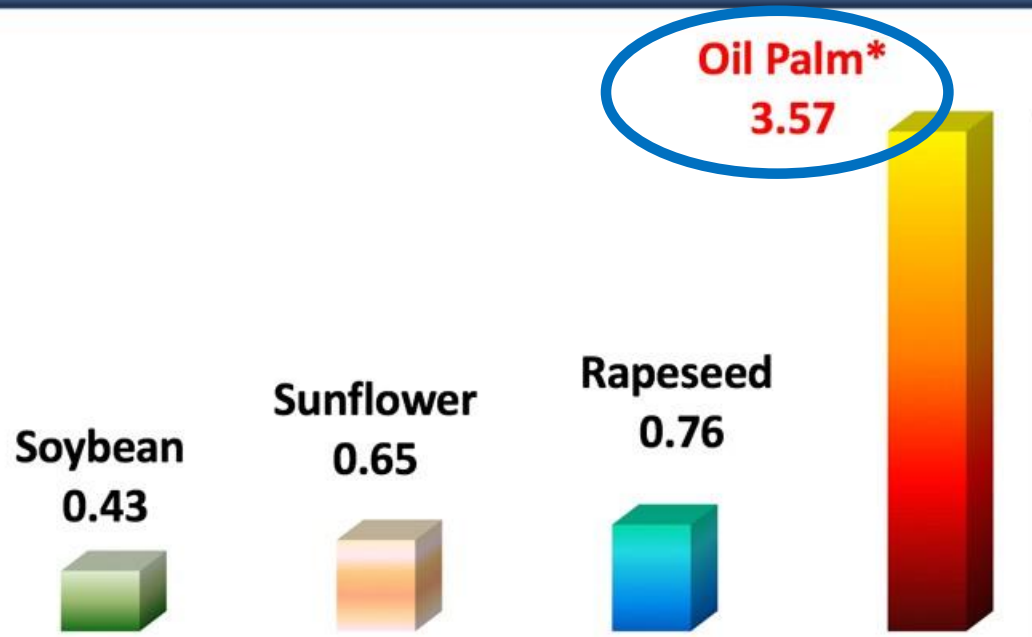
TAPPI

# OIL YIELDS IN 2016 (tonne/ha)




*for both palm oil (3.22 tonnes/ha) & palm kernel oil (0.35 tonne/ha)
Note: For Malaysian oil palm, the total oil yield was 3.85 (palm oil 3.38 tonne/ha & palm kernel oil 0.39 tonne/ha)

*Source : Oil World Database (Dec 2016)*

- Through Genome Science, Sime Darby has produced planting material that has the ability to produce oil yields of more than 11 tonnes per hectare.
- The focus is yield increase rather than land expansion.

As a perennial tree crop, oil palm has the highest oil yield as compared to other oil crops. It is 5-8 times more productive as compared to other oil crops. Less land is also required to produce equivalent tonnage of vegetable oil.
Its high yield ensures there is consistent supply to meet global demand.

*http://www.mpoc.org.my/Palm_Oil_Fact_Slides.aspx*

MPOC

**Malaysia is the second largest palm oil producer. In 2015:**

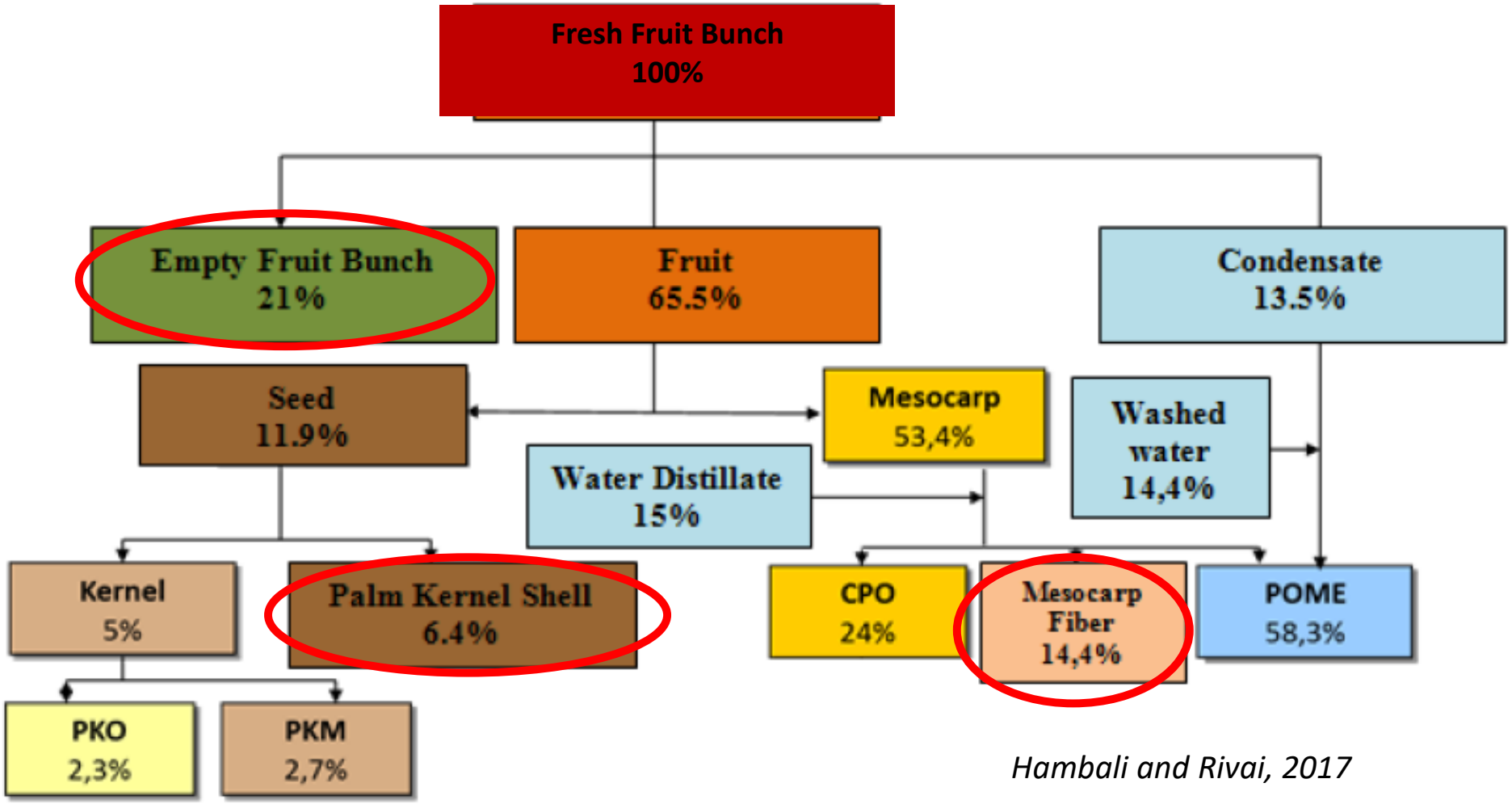
**Oil palm plantation area in Malaysia：$5.6 \times 10^6$ ha**

**CPO production： $19.96 \times 10^6$ tonnes**

**FFB yield: 18.5 tonnes / ha**

**TOTAL FFB processed: $103.6 \times 10^6$ tonnes**

https://phys.org/news/2017-10-oil-palm-blocks-good.html




*Hambali and Rivai, 2017*

**<u>Availability:</u>**

**OPEFB: 21.8 million tonnes**

**OPMF: 14.9 million tonnes**

# Resources available @ Palm Oil Industry…

## 1) Biomass

| Biomass type | Description | Site of production |
|---|---|---|
| Fronds | Leaves of oil palm tree | Plantation |
| Trunks | Tree trunks available at end of plantation lifecycle | Plantation |
| EFB | Remains after removal of palm fruits | Mill |
| Shells (PKS) | Remains after palm kernel oil extraction | Mill |
| Fiber (MF) | Remains after CPO extraction from fruit bunches | Mill |
| POME | Liquid by-product from sterilisation and milling process of FFB | Mill |

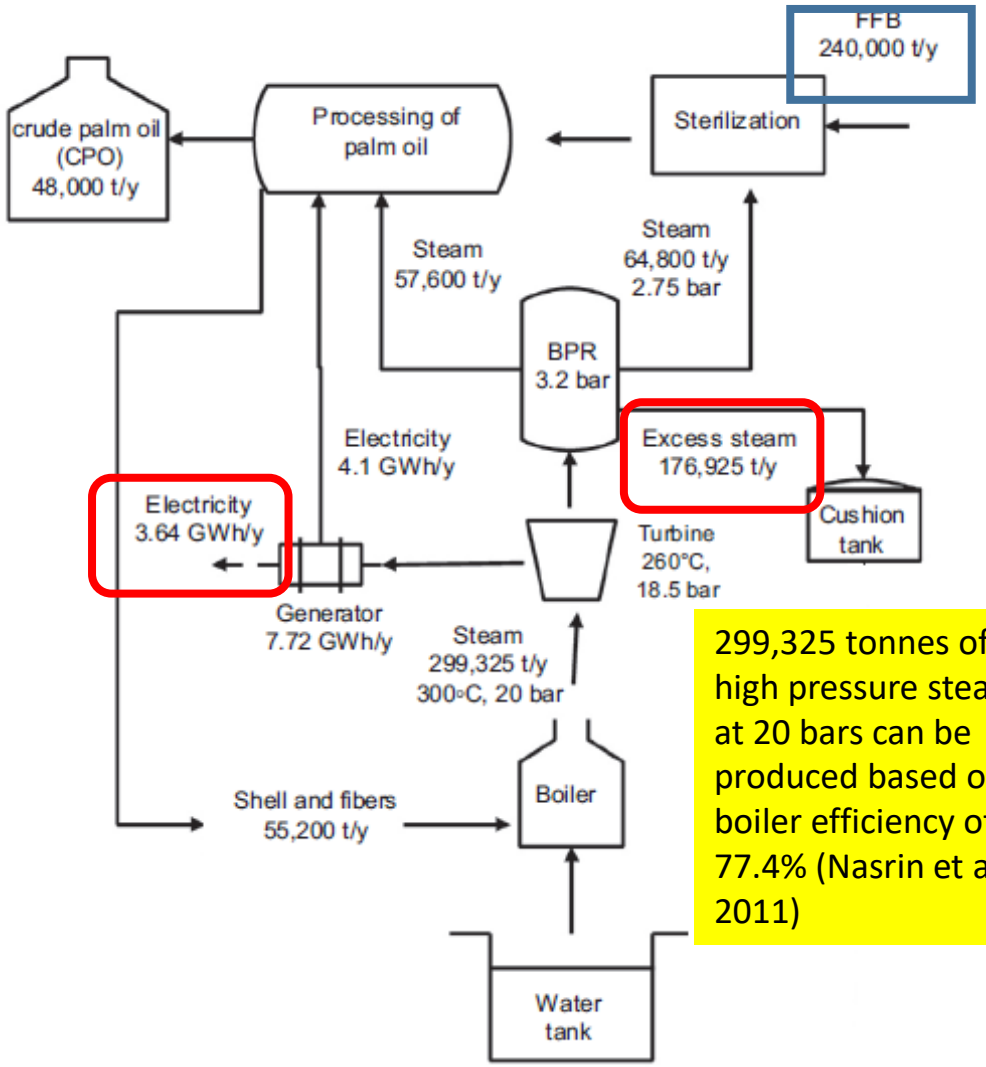
Excerpt from National Biomass Strategy 2020 (AIM, 2013)

# 2) Excess steam energy

- **Average processing capacity of a mill: 240,000 t FFB/y (MPOB, 2013)**

Estimated excess energy available at an average size palm oil mill:

- ~ 170,000 t/y steam
- 3.64 GWh/y




299,325 tonnes of high pressure steam at 20 bars can be produced based on boiler efficiency of 77.4% (Nasrin et al., 2011)

**Figure. Source of energy at palm oil mill.**

*Excerpt from Abdullah et al. (2016). Energy Conversion and Management, 108, 233-242.*

*(http://bepi.mpob.gov.my/index.php/statistics/sectoral-status/120-sectoral-status-2013/619-number-a-capacities-of-palm-oil-sectors-2013)*

# Utilization of these two resources for bio/nanomaterials:

- ❑Business as Usual (BaU) for the palm oil industry
- ❑Readily available, non-wood resources for generation of renewable materials
- ❑RSPO certification
- ❑SDGs

# ISSUES AND CHALLENGES IN PRODUCING CELLULOSE NANOFIBRILS (CNF)

- Raw material availability
- High energy consumption
  - In the range of 5 – 30 kWh/kg (Josset et al., 2014), depending on the type of mechanical process.
    - ✓ **Homogenizer:** energy-intensive, high pressure drop, fiber length causes entanglement and clogging
    - ✓ **Microfluidizer:** fiber length causes entanglement and clogging
    - ✓ **Microgrinding:** disk maintenance can be drawback, but fiber shortening pretreatment may not be required *Spence et al. (2011)*
- Low productivity
  - Low solid content processed per unit time (kg/h) due to clogging and high viscosity.

| Mechanical process | Solid content (wt %) | Reference |
|---|---|---|
| Homogenization | 0.7 | Spence et al. (2011) |
| | 0.3 | Gunawardhana et al. (2017) |
| Microfluidization | 0.7 | Spence et al. (2011) |
| | 1.5 | Hinestroza et al. (2019) |
| Microgrinding / Wet disc milling | 3.0 | Spence et al. (2011) |
| | 2.0 | Josset et al. (2014) |
| | 3.0 | University of Maine |

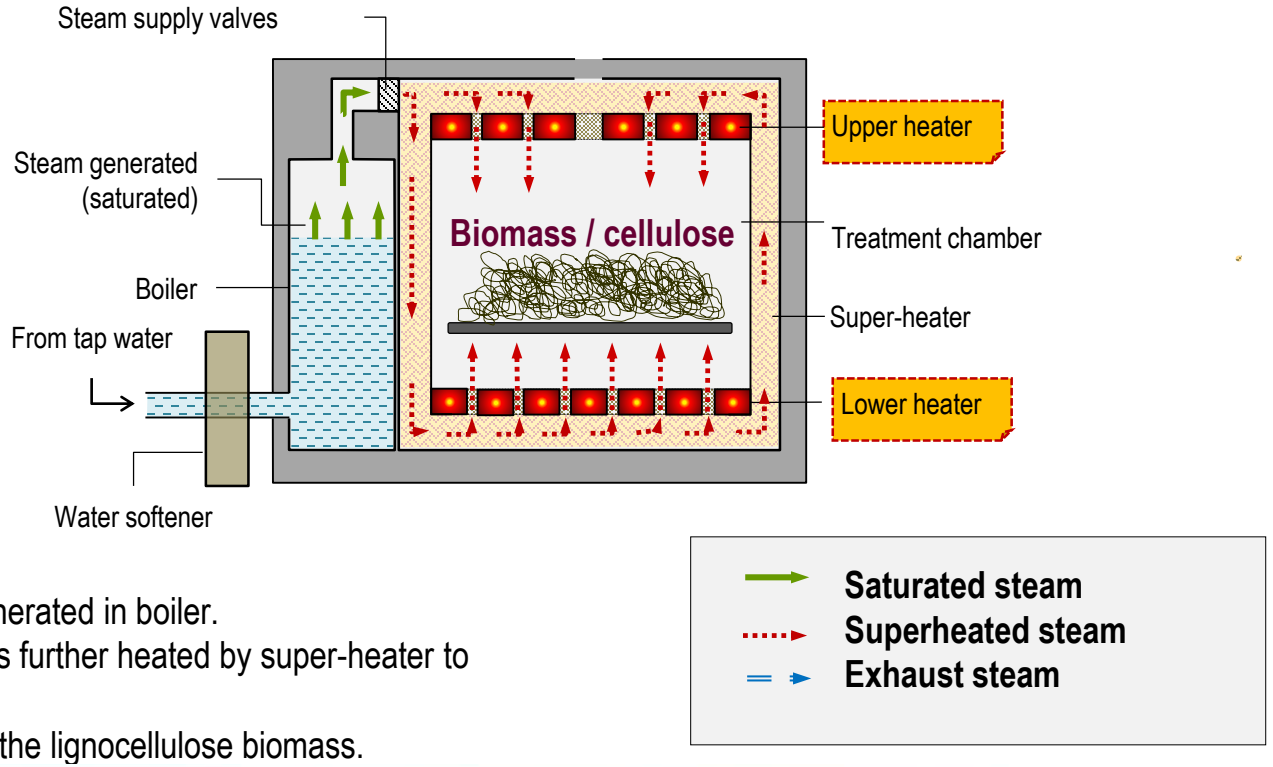
Pretreatment is needed prior to nanofibrillation to allow for higher solid content of cellulose to be processed, without increasing the energy consumption (kWh/kg).

RESOURCES FROM PALM OIL MILL CAN BE USED TO OVERCOME THE ABOVE ISSUES..

# PRETREATMENT OF CELLULOSE BY SUPERHEATED STEAM (SHS)

**Patents pending: PCT/JP2012/007427 & PI 2016702175**
**(Developed together with Prof. Shirai and Prof. Nishida of Kyushu Institute of Technology, Japan through SATREPS project)**

**Superheated steam:** a high-temperature **vapor** generated by heating the saturated **steam**.




1. Saturated steam generated in boiler.
2. Steam produced was further heated by super-heater to produce SHS.
3. SHS is subjected to the lignocellulose biomass.

*Picture courtesy of Sharip et al., 2016. RSC Adv., 2016, 6, 84672*

# SUPERHEATED STEAM (SHS) PRETREATMENT

**ADVANTAGES OF SHS PRETREATMENT:**

- **Reduce the cellulose DP (and viscosity)**
- **Safe for operation: atm pressure.**
- **Ready for industrial application: large scale SHS facility is available.**

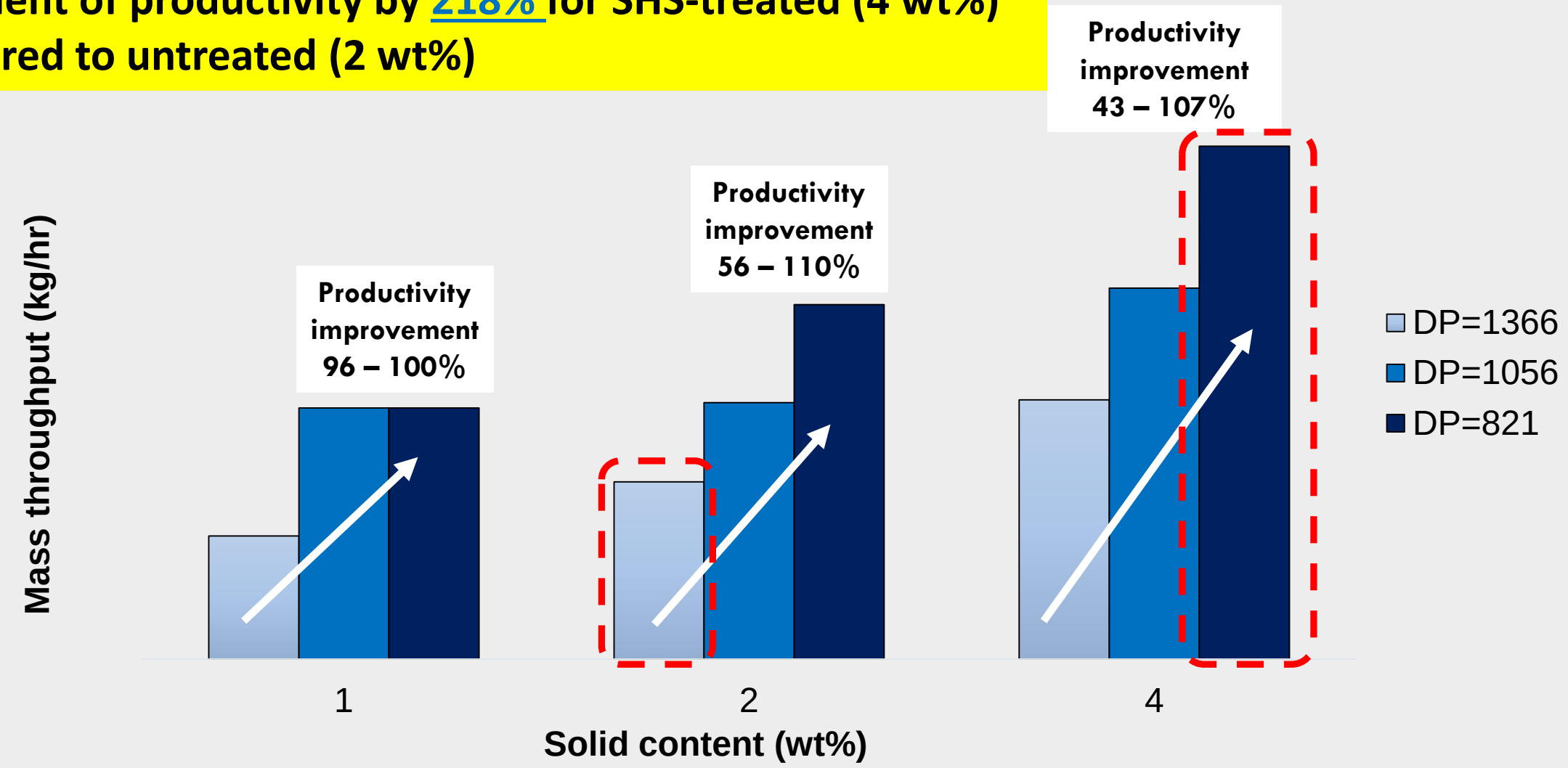
# REDUCTION OF CELLULOSE DP BY SHS PRETREATMENT

SHS pretreatment was used to reduce cellulose DP prior to WDM process.

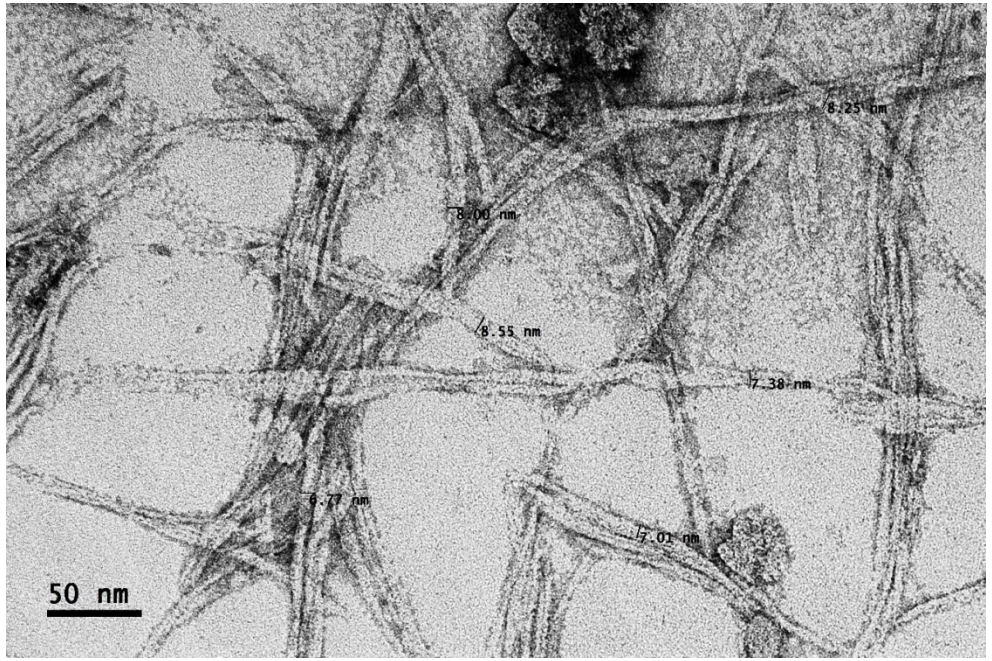
| OPEFB cellulose | DP |
|---|---|
| Untreated | **1,366** |
| SHS-treatment 1 | **1,056** |
| SHS treatment 2 | **821** |

# Improvement in CNF productivity with DP reduction

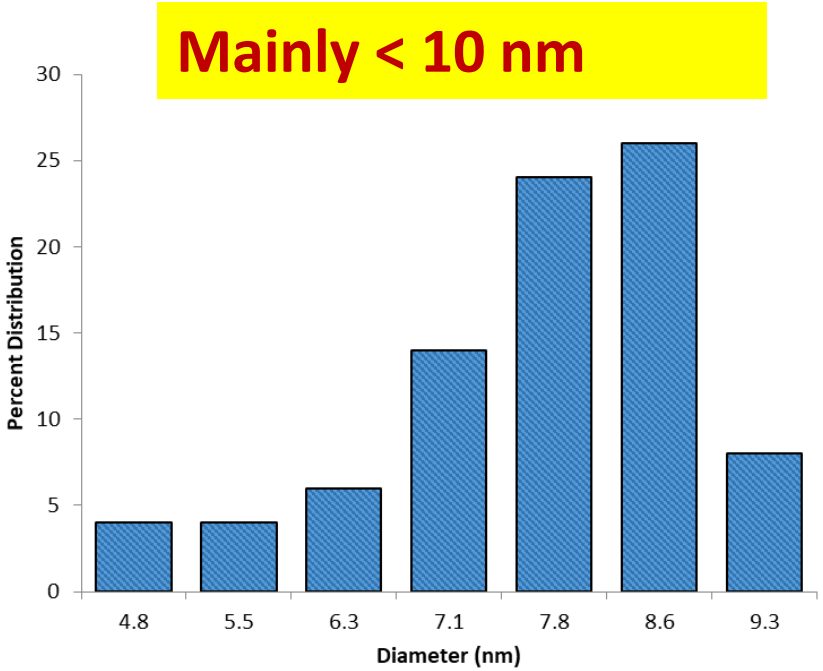
**Increment of productivity by 218% for SHS-treated (4 wt%) compared to untreated (2 wt%)**



# SIZE DISTRIBUTION (TEM)




(A) TEM image of CNF from Oil Palm Empty Fruit Bunch




(B) Diameter size distribution

# Wetting properties of CNF films

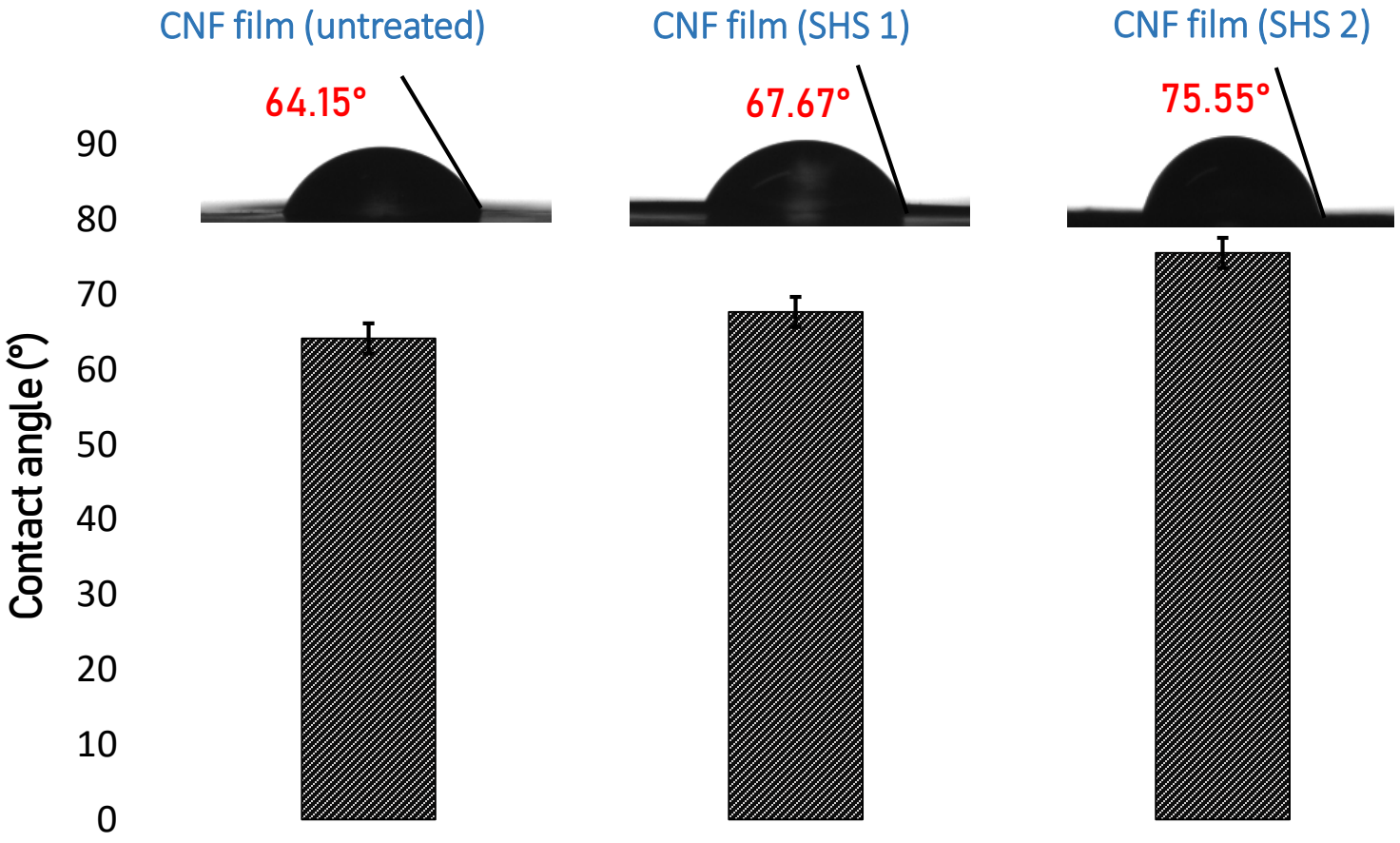



**Fig.** Contact angle of CNF films with and without SHS pretreatment

α < 90° = hydrophilic
All CNF films showed good wetting properties

Example: Perfect wetting **(α = 0°)**

Contact angle (CA) for **micropaper**

# Conclusions

- Superheated steam (SHS) pretreatment **improved the productivity** and **reduced the energy consumption** during CNF production **by more than 200%**.
- CNF with **various mechanical properties** can be obtained by SHS pretreatment.
- **Enhanced optical properties and improved contact angle** values can be related with smoother surface of CNF film prepared by SHS-pretreated cellulose.
- SHS pretreatment and utilization of oil palm biomass is the way forward for CNF production in Malaysia with the advantage of contributing to SDGs and RSPO certification.

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- Students

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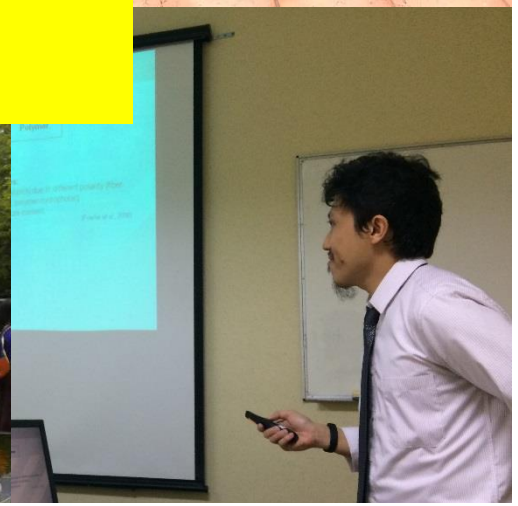
- Prof. Dr Haruo Nishida
- Assoc. Prof. Dr Yoshito Ando

# STUDENTS INVOLVED IN THIS PROJECT



# Thank you

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