The Effects of Piper nigrum Soaking Temperature, Density, and Sacking on its Stiffness Measured Using our Tailor Made Pepper Stiffness Instrument

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Abstract: This study aims to measure the effects of Piper nigrum soaking temperature, density, and sacking on its stiffness using our tailor-made Piper nigrum stiffness instrument. The soaking water temperature is classified as low (room water temperature), moderate (60 °C), and high temperature (90 °C). The Piper nigrum density is grouped into low (90 gr/2 l), moderate (90 gr/1.5 l), and high density (90 gr/1 l). The Piper nigrum is divided into sacking and non-sacking. The experiment is conducted in three batches. Hence, the total samples are 54 (3 x 3 x 2 x 3). The first batch (18 samples) is divided into three temperature groups, three density groups, and two sacking groups. The second and third samples of temperature groups are treated further with moderate or high temperatures, respectively, for five minutes. The first batch is lifted from the soaking tubs for natural drying. These processes are repeated for the second and third batches. The stiffness measurements, from 11352.56 N/m to 20356.32 N/m, were obtained. The results tested using three-way Anova with a 5 % (0.05) significance level (95 % confidence level) showed that there were significant interactions among Piper nigrum soaking temperature, density, and sacking on its stiffness.

Keywords: density; Piper nigrum pericarp stiffness; Piper nigrum stiffness instrument; sacking; soaking temperature

1. Introduction

Energy is vital to increasing the quality of Piper nigrum. All processes in producing Piper nigrum products need energy[1)]. These roles are valid for both traditional and modern processing systems that use many controllers inside[2)]. The soaking process in this paper is one example of energy saving when producing Piper nigrum products.

Piper nigrum, the king of spices[3)], is very useful for traditional Indonesian medicine to cure various ailments 4), such as an antioxidant and anti-inflammatory[5,6)]. There are some kinds of Piper nigrum, but the most famous are the black Piper nigrum (black gold)[7)] and the white Piper nigrum. The main feature that differentiates white and black Piper nigrum is the existence of their pericarp, which influences their piperine content[8)]. Unlike the black Piper nigrum[9)], the white Piper nigrum[10)] has no pericarp. The pericarp is considered a significant determinant of colour intensity, texture and yield of Piper nigrum[11)]. Its pericarp is intentionally thrown away, usually by soaking it. Hence, the efficiency of producing white Piper nigrum is lower than that of black Piper nigrum[12)], typically 25-28 % compared to 33-37 %[13)]. At the same quantity, the piperine percentage for white Piper nigrum in Lampung, Indonesia, is typically higher than that of black Piper nigrum[14)].

The removal of the Piper nigrum pericarp can be done with chemical, physical, or biological methods[15)]. The majority (99.9%) of pepper plantations in Indonesia are smallholder plantations[16)], so the famous method, especially in Indonesia, is using a soaking process. The retting method is defined as the fibre extraction that involves decomposition by the microbiological method of the cementing material or dissolution by chemical method in which the fibre bundles are loosened from the adhering tissues and extracted by washing[17)]. This process generally takes a time that is too long, 10-14 days[18)]. Therefore, the chemical, physical, and biological methods are combined to accelerate the soaking process. For example, the soaking

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process is combined with boiling[19]. Alternatively, adding some organisms, such as bacteria, especially Bacillus subtilis[20].

The soaking process is usually carried out in rivers[21]. This habit is risky both for the workers, the Piper nigrum itself, and the river. The workers might be swept away by a sudden flood, especially in big rivers. Rivers are usually dirty and polluted, and unneeded materials in the river water may contaminate the Piper nigrum. On the other hand, the decomposed material from the Piper nigrum can pollute the river water, particularly in the aspects of turbidity, pH, dissolved oxygen, and chemical oxygen demand[22], and reduce the colour quality[23]. Durian waste husks can be used as an adsorbent to improve soaking water during the retting process of piper nigrum[24]. This technique, however, is not suitable for soaking in rivers.

In order to avoid soaking in rivers, The Development of Integrated Farming System in Upland Areas (UPLAND) Project has developed some soaking tubs in Purbalingga Regency, Central Java Province, Indonesia 1). So far, unfortunately, there are no records showing that the utilization of soaking tubs can improve the Piper nigrum quality measured from the hardness aspect. The golden goal for the soaking process is to reduce the hardness of the Piper nigrum pericarp. Therefore, the Piper nigrum pericarp can be peeled off easily to make the white Piper nigrum.

There are several factors that influence the hardness of Piper nigrum pericarps, including temperature, density (concentration), soaking time, sacking, additional acid material, bacteria, and mechanical flow. This study aims to obtain the effects of Piper nigrum soaking temperature, density, and sacking on its hardness. However, the authors prefer to use stiffness for this study for some reasons, which will be explained later. The dependent variable was measured using our tailor-made pepper stiffness instrument. Hardness refers to the resistance of a material to deformation or penetration[25]. Especially on the sacking aspect, this study can answer the research question of whether soaking tubs are beneficial or not in reducing the Piper nigrum pericarp.

There are some famous methods to measure material hardness, such as Vickers, Brinell, Rockwell, Knoop, and Berkovich[26]. These methods are usually used for non-organic materials such as metal and plastic, some of which are made in portable form[27-29]. The hardness tester is also used for organic materials such as fruits[30]. The hardness tester for fruits can be measured based on a texture analyzer[31] and tactile method[32,33]. So far as the authors know, however, there is no method dedicated to measuring the hardness of Piper nigrum pericarp, especially after the soaking process. So, for this study, the authors also developed a Piper nigrum pericarp hardness instrument first.

The common hardness testers are based on the force on a certain area. So, even though there are many hardness unities, they can be converted into Newton/m^2. Our tailor-made Piper nigrum hardness instrument works based on the displacement that reacts to the force that works on that object (Piper nigrum in this case). This instrument is dedicated to this purpose to the common hardness testers, but their unity is different. Our instrument has a unity Newton/m. Hence, as many of our tailor-made instruments are in control[34,35], measurement[36,37], and software[38], the Piper nigrum stiffness instrument also has a special purpose. To avoid misunderstanding hardness in Newton/m^2, the authors use the word stiffness, the ratio of load to deflection Newton/m[39].

2. Methodology

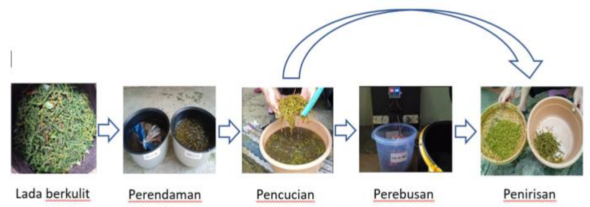
2.1. Data Gathering

2.1.1. Experiment Process

Some preparations (Figure 1) are made before conducting the main activity in this study, namely the Piper nigrum pericarp stiffness as a function of temperature, density, and sacking. Generally, stiffness and compression characteristics are extremely important parameters for size reduction operations40). In this study, it is an important parameter for producing white Piper nigrum. The preparation includes raw material procurement, soaking, washing, heating (boiling), and draining.

We have to prepare the raw material, namely the Piper nigrum. Mature and ripe pepper berries are used for white pepper production due to the stiffness of the peppercorn and thinner outer skin[41]. For this sake, the Piper nigrum was picked directly from the Piper nigrum field in Purbalingga. This method was also used to reduce the possibility of Piper nigrum damage due to the transportation process via a freight forwarding agent. Before the soaking process, the branches, leaves, and dirt of Piper nigrum should be thrown away first. This activity should be carried out because white pepper is of better quality if the stalk is removed first[42]. The pericarp, stalks, and leaves of Piper nigrum are usually treated as waste materials[43,44].

The utilization of mechanical tools has the potential to damage the Piper nigrum berries[45]. Hence, the Piper nigrum farmers tend to use soaking techniques rather than



Raw material	Soaking	Washing	Boiling	Draining

Fig. 1: Experiment process

mechanical tools. The soaking was conducted for six days. After soaking, the Piper nigrum was washed slightly. This action was to make sure that the Piper nigrum was clean.

Some Piper nigrum were heating. The heating was classified into two groups, 60 °C and 100 °C. Water was heated at 60 °C or 100 °C. Then, the Piper nigrum was poured into the heated water for 5 minutes.

All Piper nigrum should be drained first. So, there was no flowing or dripping water from the Piper nigrum tube. In this phase, the Piper nigrum pericarp stiffness was ready to be measured.

2.1.2. Measurement Process

In this study, Piper nigrum stiffness cannot be measured using a common stiffness tester, but a special one is needed (Figure 2) for some reasons. 1) There is a variation in the ripe fruit stiffness of Piper nigrum46). So, the measurement stiffness of Piper nigrum can not be represented by a single berry. The Piper nigrum pericarp would also like to be measured in the collection of fruit after they experience the soaking process.2) The stiffness measurement is also dependent on the face sheet47), which, in this study, is not as flat as the common objects.

All Piper nigrum that has been drained has become almost dry. The almost dry Piper nigrum then was weighed first. Its weight should be made uniformly at 90 gr and a distance of 10 cm. Then, it was entered into the Piper nigrum tube. Shake the tube slightly so the Piper nigrum berries are in their proper positions. Place the piston surface into the Piper nigrum surface in the Piper nigrum tube. Measure the distance of the piston canopy using a laser distance meter (LDM, a handheld device that uses a laser beam to measure the distance between the Piper nigrum surface and the piston canopy) to obtain the initial measurement.

Lift the piston. Lock the piston canopy so it cannot move up and down. Place the load into the piston canopy centre. Drop the piston with its load into the Piper nigrum surface in the Piper nigrum tube. Remeasure the distance of the piston canopy using the LDM to obtain the final measurement.

Subtract the first distance measurement with the second distance measurement. The distance difference (length) is proportional to the compression experienced by the Piper nigrum in the Piper nigrum tube. The flowchart of all these processes is presented in Figure 3.

Weighing for Almost dry Piper Nigrum | Length measurement

Fig. 2: Measurement process

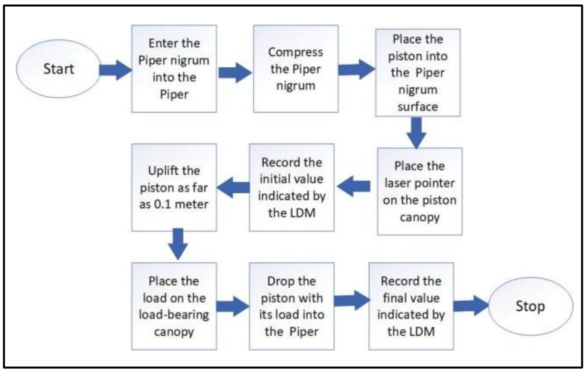


Fig. 3: The flowchart of the measurement process.

The design of the stiffness instrument for this study is available on the patent of this paper[48]. Hence, there is no further discussion in this paper.

The stiffness instrument in this study is a new one. Therefore, it cannot be calibrated directly using its standard. What should be conducted is by calibrating its factors. Two dominant variables that influence the stiffness of the instrument were mass and distance. These units can be calibrated at a formal calibration laboratory. The calibration result shows that a 1000 g mass was calibrated to 1020.47, with an error of 2.047%. The accuracy of LDM was 1.5 mm for the range of 40 m, or the LDM accuracy was 0.00375 %. It can be seen that the mass error is much higher than the distance error. Hence, the accuracy of this stiffness instrument is around 2%.

2.2. Data Analysis

2.2.1. Stiffness conversion

The deformation modulus expresses the stiffness of the material in N/m[42]. In this study, however, the stiffness is stated as N/m[49] following the international system for units, where if the force uses Newton (N), then the distance uses a meter (m).

The distances were then converted into stiffness by dividing the force by the distance. Hence, stiffness is inversely proportional to the displacement measurement.

2.2.2. Anova

Anova (analysis of variance) is a statistical technique for analyzing mean differences[50]. The Anova used in this study is a three-way Anova with a 5 % significance level (95 % confidence level) and many parameters.

The total sum of squares is

$$SST = \sum_{n=1}^{n} X_n{}^2 \qquad (1)$$

The treatment sum of squares is

$$SST_r = \frac{\left(\sum_{t=1}^{3}\sum_{d=1}^{3}\sum_{s=1}^{2}\sum_{b=1}^{3} X_{tdsb}\right)^2}{n} \qquad (2)$$

The error sum of squares is equal to the total sum of squares minus the treatment sum of squares[51)] Hence it is represented as:

$$SSE = SST - SST_r \quad (3)$$

The temperature sum of squares is

$$SSE_t = \frac{\left(\sum_{d=1}^{3}\sum_{s=1}^{2}\sum_{b=1}^{3} X_{t1dsb}\right)^2}{n_t} + \frac{\left(\sum_{d=1}^{3}\sum_{s=1}^{2}\sum_{b=1}^{3} X_{t2dsb}\right)^2}{n_t} + \frac{\left(\sum_{d=1}^{3}\sum_{s=1}^{2}\sum_{b=1}^{3} X_{t3dsb}\right)^2}{n_t} - SST_r \quad (4)$$

The density sum of squares is

$$SSE_d = \frac{\left(\sum_{t=1}^{3}\sum_{s=1}^{2}\sum_{b=1}^{3} X_{td1sb}\right)^2}{n_d} + \frac{\left(\sum_{t=1}^{3}\sum_{s=1}^{2}\sum_{b=1}^{3} X_{td2sb}\right)^2}{n_d} + \frac{\left(\sum_{t=1}^{3}\sum_{s=1}^{2}\sum_{b=1}^{3} X_{td3sb}\right)^2}{n_d} - SST_r \quad (5)$$

The sacking sum of squares is

$$SSE_s = \frac{\left(\sum_{t=1}^{3}\sum_{d=1}^{3}\sum_{b=1}^{3} X_{tds1b}\right)^2}{n_s} + \frac{\left(\sum_{t=1}^{3}\sum_{d=1}^{3}\sum_{b=1}^{3} X_{tds2b}\right)^2}{n_s} - SST_r \quad (6)$$

The temperature and density interaction sum of squares is

$$SSE_{td} = \frac{\left(\sum_{s=1}^{2}\sum_{b=1}^{3} X_{t1d1sb}\right)^2}{n_{sb}} + \frac{\left(\sum_{s=1}^{2}\sum_{b=1}^{3} X_{t1d2sb}\right)^2}{n_{sb}} + \frac{\left(\sum_{s=1}^{2}\sum_{b=1}^{3} X_{t1d3sb}\right)^2}{n_{sb}} + \frac{\left(\sum_{s=1}^{2}\sum_{b=1}^{3} X_{t2d1sb}\right)^2}{n_{sb}} + \frac{\left(\sum_{s=1}^{2}\sum_{b=1}^{3} X_{t2d2sb}\right)^2}{n_{sb}} + \frac{\left(\sum_{s=1}^{2}\sum_{b=1}^{3} X_{t2d3sb}\right)^2}{n_{sb}} + \frac{\left(\sum_{s=1}^{2}\sum_{b=1}^{3} X_{t3d1sb}\right)^2}{n_{sb}} + \frac{\left(\sum_{s=1}^{2}\sum_{b=1}^{3} X_{t3d2sb}\right)^2}{n_{sb}} + \frac{\left(\sum_{s=1}^{2}\sum_{b=1}^{3} X_{t3d3sb}\right)^2}{n_{sb}} - SST_r - SSE_t - SSE_d \quad (7)$$

The temperature and sacking interaction sum of squares is

$$SSE_{ts} = \frac{\left(\sum_{d=1}^{3}\sum_{b=1}^{3} X_{t1ds1b}\right)^2}{n_{db}} + \frac{\left(\sum_{d=1}^{3}\sum_{b=1}^{3} X_{t1ds2b}\right)^2}{n_{db}} + \frac{\left(\sum_{d=1}^{3}\sum_{b=1}^{3} X_{t2ds1b}\right)^2}{n_{db}} + \frac{\left(\sum_{d=1}^{3}\sum_{b=1}^{3} X_{t2ds2b}\right)^2}{n_{db}} + \frac{\left(\sum_{d=1}^{3}\sum_{b=1}^{3} X_{t3ds1b}\right)^2}{n_{db}} + \frac{\left(\sum_{d=1}^{3}\sum_{b=1}^{3} X_{t3ds2b}\right)^2}{n_{db}} - SST_r - SSE_t - SSE_s \quad (8)$$

The density and sacking interaction sum of squares is

$$SSE_{ds} = \frac{\left(\sum_{t=1}^{3}\sum_{b=1}^{3} X_{td1s1b}\right)^2}{n_{tb}} + \frac{\left(\sum_{t=1}^{3}\sum_{b=1}^{3} X_{td1s2b}\right)^2}{n_{tb}} + \frac{\left(\sum_{t=1}^{3}\sum_{b=1}^{3} X_{td2s1b}\right)^2}{n_{tb}} + \frac{\left(\sum_{t=1}^{3}\sum_{b=1}^{3} X_{td2s2b}\right)^2}{n_{tb}} + \frac{\left(\sum_{t=1}^{3}\sum_{b=1}^{3} X_{td3s1b}\right)^2}{n_{tb}} + \frac{\left(\sum_{t=1}^{3}\sum_{b=1}^{3} X_{td3s2b}\right)^2}{n_{tb}} - SST_r - SSE_d - SSE_s \quad (9)$$

The temperature, density and sacking interaction sum of squares is

$$SSE_{tds} = \frac{\left(\sum_{b=1}^{3} X_{t1d1s1b}\right)^2}{n_b} + \frac{\left(\sum_{b=1}^{3} X_{t1d1s2b}\right)^2}{n_b} + \frac{\left(\sum_{b=1}^{3} X_{t1d2s1b}\right)^2}{n_b} + \frac{\left(\sum_{b=1}^{3} X_{t1d2s2b}\right)^2}{n_b} + \frac{\left(\sum_{b=1}^{3} X_{t1d3s1b}\right)^2}{n_b} + \frac{\left(\sum_{b=1}^{3} X_{t1d3s2b}\right)^2}{n_b} + \frac{\left(\sum_{b=1}^{3} X_{t2d1s1b}\right)^2}{n_b} + \frac{\left(\sum_{b=1}^{3} X_{t2d1s2b}\right)^2}{n_b} + \frac{\left(\sum_{b=1}^{3} X_{t2d2s1b}\right)^2}{n_b} + \frac{\left(\sum_{b=1}^{3} X_{t2d2s2b}\right)^2}{n_b} + \frac{\left(\sum_{b=1}^{3} X_{t2d3s1b}\right)^2}{n_b} + \frac{\left(\sum_{b=1}^{3} X_{t2d3s2b}\right)^2}{n_b} + \frac{\left(\sum_{b=1}^{3} X_{t3d1s1b}\right)^2}{n_b} + \frac{\left(\sum_{b=1}^{3} X_{t3d1s2b}\right)^2}{n_b} + \frac{\left(\sum_{b=1}^{3} X_{t3d2s1b}\right)^2}{n_b} + \frac{\left(\sum_{b=1}^{3} X_{t3d2s2b}\right)^2}{n_b} + \frac{\left(\sum_{b=1}^{3} X_{t3d3s1b}\right)^2}{n_b} + \frac{\left(\sum_{b=1}^{3} X_{t3d3s2b}\right)^2}{n_b} - SSST_r - SSE_t - SSE_d - SSE_s \quad (10)$$

The internal sum of squares is

$$SSE_i = SSE - (SSE_t + SSE_d + SSE_s + SSE_{td} + SSE_{ts} + SSE_{ds} + SSE_{tds}) \quad (11)$$

The total number of degrees of freedom

$$DF_{tot} = n_{tot} - 1 \quad (12)$$

The temperature number of degrees of freedom

$$DF_t = n_t - 1 \quad (13)$$

The density number of degrees of freedom

$$DF_d = n_d - 1 \quad (14)$$

The sacking number of degrees of freedom

$$DF_s = n_s - 1 \quad (15)$$

The temperature vs density number of degrees of freedom

$$DF_{td} = (n_t - 1)(n_d - 1) \quad (16)$$

The temperature vs sacking number of degrees of freedom

$$DF_{ts} = (n_t - 1)(n_s - 1) \quad (17)$$

The density vs sacking number of degrees of freedom

$$DF_{ds} = (n_d - 1)(n_s - 1) \quad (18)$$

The temperature vs density vs sacking number of degrees of freedom

$$DF_{tds} = (n_t - 1)(n_d - 1)(n_s - 1) \quad (19)$$

The internal number of degrees of freedom

$$DF_i = DF_{tot} - (DF_t + DF_d + DF_s + DF_{td} + DF_{ts} + DF_{ds} + DF_{tds}) \quad (20)$$

There are three kinds of mean squares, namely the main effect, interaction, and internal mean squares. The main effect means square consists of temperature (MS_t), density (MS_d), and sacking (MS_s) mean squares. The interaction means squares comprise the interaction between temperature and density (MS_{td}), temperature and sacking (MS_{ts}), density and sacking (MS_{ds}), and among temperature, density, and sacking (MS_{tds}). Another main square, called the total mean square is no longer used for further calculation. Hence, it is not presented in the following formulas.

$$MS_t = \frac{SSE_t}{DF_t} \quad (21)$$

$$MS_d = \frac{SSE_d}{DF_d} \quad (22)$$

$$MS_s = \frac{SSE_s}{DF_s} \quad (23)$$

$$MS_{td} = \frac{SSE_{td}}{DF_{td}} \quad (24)$$

$$MS_{ts} = \frac{SSE_{ts}}{DF_{ts}} \quad (25)$$

$$MS_{ds} = \frac{SSE_{ds}}{DF_{ds}} \quad (26)$$

$$MS_{tds} = \frac{SSE_{tds}}{DF_{tds}} \quad (27)$$

$$MS_i = \frac{SSE_i}{DF_i} \quad (28)$$

2.2.3. Hypothesis Testing

Hypothesis testing is obtained by comparing the experiment F (F_e) values with statistic (theoretical, F_s) F (Fisher-Snedecor). In this study, there are seven null hypotheses (Hypothesis 1 – Hypothesis 7). The seven hypotheses are:

Water temperature has no significant effect on the stiffness of *Piper nigrum* pericarp.

Tub density has no significant effect on the stiffness of *Piper nigrum* pericarp.

Pepper sacking has no significant effect on the stiffness of *Piper nigrum* pericarp.

There is no significant interaction between water temperature and tub density that affects the stiffness of *Piper nigrum* pericarp.

There is no significant interaction between water temperature and *Piper nigrum* sacking that affects the stiffness of *Piper nigrum* pericarp.

There is no significant interaction between tub density and *Piper nigrum* sacking that affects the stiffness of *Piper nigrum* pericarp.

There is no significant interaction among water temperature, tub density, and *Piper nigrum* sacking that affects the stiffness of *Piper nigrum* pericarp.

There are two kinds of Fe values, namely the main effect and interaction F values. The main effect Fe value consists of the mean square comparisons between the temperature and internal ($F_{eDF_t:DF_i}$), density and internal ($F_{eDF_d:DF_i}$), and sacking and internal ($F_{eDF_s:DF_i}$). The interaction Fe comprises the mean square comparisons between temperature and density interaction and internal ($F_{eDF_{td}:DF_i}$), temperature and sacking interaction and internal ($F_{eDF_{ts}:DF_i}$), density and sacking interaction and internal ($F_{eDF_{ds}:DF_i}$), and temperature, density, and sacking interaction and internal ($F_{eDF_{tds}:DF_i}$).

$$F_{eDF_t:DF_i} = \frac{MS_t}{MS_i} \quad (29)$$

$$F_{eDF_d:DF_i} = \frac{MS_d}{MS_i} \quad (30)$$

$$F_{eDF_s:DF_i} = \frac{MS_s}{MS_i} \quad (31)$$

$$F_{eDF_{td}:DF_i} = \frac{MS_{td}}{MS_i} \quad (32)$$

$$F_{eDF_{ts}:DF_i} = \frac{MS_{ts}}{MS_i} \quad (33)$$

$$F_{eDF_{ds}:DF_i} = \frac{MS_{ds}}{MS_i} \quad (34)$$

$$F_{eDF_{tds}:DF_i} = \frac{MS_{tds}}{MS_i} \quad (35)$$

The magnitude of F_s is obtained from the F table that is usually available in many inferential statistic books. Two things make the magnitude of F_s usually different. These are the row effect and column effect on the F table. The row effect depended on the DF of the main effect and interaction effect. The column effect is caused only by the internal DF.

Each of the hypotheses will be accepted based on the following formulas:

$$F_{eDF_t:DF_i} \leq F_{s2:36} \quad (36)$$

$$F_{eDF_d:DF_i} \leq F_{s2:36} \quad (37)$$

$$F_{eDF_s:DF_i} \leq F_{s1:36} \quad (38)$$

$$F_{eDF_{td}:DF_i} \leq F_{s4:36} \quad (39)$$

$$F_{eDF_{ts}:DF_i} \leq F_{s2:36} \quad (40)$$

$$F_{eDF_{ds}:DF_i} \leq F_{s2:36} \quad (41)$$

$$F_{eDF_{tds}:DF_i} \leq F_{s4:36} \quad (42)$$

If the correct F_s is not obtained on the F table, then a linear interpolation is carried out from the two nearest values. For example, there is no DF= 36 for the column of the F table (Table 1).

Table 1: Interpolation for DB= 36 on the column of the F table

$F_{e1:36}$	$F_{s1:30}$	$F_{s1:40}$	$F_{s1:36}$	$F_{e2:36}$	$F_{s2:30}$	$F_{s2:40}$	$F_{s2:36}$	$F_{e4:36}$	$F_{s4:30}$	$F_{s4:40}$	$F_{s4:36}$
Experiment Result (ER)	250	251	250.6	ER	19.46	19.47	19.467	ER	5.74	5.71	5.728

Table 2: The stiffness measurement results

Temperature (t)	Density (d)	Sacking (s_1) X_n or X_{tdsb}			Not Sacking (s_2) X_n or X_{tdsb}		
	d1	X1111	X1112	X1113	X1121	X1122	X1123
		19677.78	15136.75	17888.89	13118.52	13416.67	12560.28
Low (t1)	d2	X1211	X1212	X1213	X1221	X1222	X1223
(30 °C)		13118.52	13416.67	15954.95	13416.67	16866.67	15136.75
	d3	X1311	X1312	X1313	X1321	X1322	X1323
		15954.95	17362.75	17362.75	14758.33	12833.33	16866.67
	d1	X2111	X2112	X2113	X2121	X2122	X2123
		20356.32	11352.56	17362.75	13728.68	15535.09	13118.52
Moderate (t2)	d2	X2211	X2212	X2213	X2221	X2222	X2223
(60 °C)		16398.15	16398.15	17888.89	12560.28	14758.33	11806.67
	d3	X2311	X2312	X2313	X2321	X2322	X2323
		12047.62	11575.16	12833.33	12833.33	13118.52	14055.56
	d1	X3111	X3112	X3113	X3121	X3122	X3123
		15136.75	15954.95	20356.32	15954.95	13728.68	14398.37
High (t3)	d2	X3211	X3212	X3213	X3221	X3222	X3223
(100 °C)		12047.62	17362.75	17362.75	16866.67	13728.68	13728.68
	d3	X3311	X3312	X3313	X3321	X3322	X3323
		14398.37	17362.75	15869.18	13728.68	13728.68	14055.56

So far, we have presented the methodology for data gathering (experiment process and measurement process) and data analysis. Then, the data obtained from the experiment process and measurement process are further analyzed and discussed in the result and discussion section. Seven answers will be obtained because there are also seven research questions presented in the hypothesis form. The seven answers to the hypothesis, however, are summarized in one sentence in the conclusion.

3. Result and discussion

3.1. Result

Based on the methodology explained before, stiffness measurement results were obtained and presented in Table 2. Totally there were 54 (3 x 3 x 2 x 3) samples, which were classified by three kinds of temperature (low, moderate, and high), three kinds of density (low, moderate, and high), two kinds of sackings (sacking and not sacking), and three batches (batch 1, batch 2, and batch 3). Hence, the Xn (sample) can be written in general form as Xtdsb or in detail from X1111 to X3323.

The raw data in Table 2 was analyzed in squared form, as presented in Table 3. Every row and column in this table were summed using either the column-to-row or row-to-column methods. In this case, both methods gave the same result.

Table 2 was also summed horizontally or vertically (Table 4). The low, moderate, or high temperature was presented as X1dsb, X2dsb, and X3dsb, respectively, where each Xn has 18 samples. The low, moderate, or high density was presented as Xt1sb, Xt2sb, and Xt3dsb, respectively, where each Xn has 18 samples. The sacking or not sacking was presented as Xtd1b and Xtd2b, respectively, where each Xn has 27 samples. The interaction between temperature and density was presented as X11sb, X12sb, X13sb, X21sb, X22sb, X23sb, X31sb, X32sb, and X33sb, respectively, where each Xn has 6 samples. The interaction between temperature and sacking was presented as X1d1b, X1d2b, X2d1b, X2d2b, X3d1b, and X3d2b, respectively, where each Xn has nine samples. The interaction between density and sacking was presented as Xt11b, Xt12b, Xt21b, Xt22b, Xt31b, and Xt32b, respectively, where each Xn has nine samples. The interaction among temperature, density, and sacking was presented as X111b, X112b, X121b, X122sb, X131b, X132b, X211b, X212b, X221b, X222sb, X231b, X232b, X311b, X312b, X321b, X322sb, X331b, and X332b, respectively where each Xn has three (triplicated) samples. The magnitude of these samples is saved in Table 4.

Some results were obtained (Table 5) by applying formulas presented in the methodology to Table 4. Six hypotheses presented in Table 5 were accepted from seven hypotheses, and two hypotheses were rejected. Hence, there was a significant interaction between water temperature, tub density, and Piper nigrum sacking that affected the stiffness of Piper nigrum pericarp.

Table 3: The stiffness measurement results

Temperature (t)	Density (d)	tds1b	Sacking (s_1) Xn			$\sum x$	tds2b	Not Sacking (s_2) Xn			$\sum X$	Grand Total
Low (t1) (30 °C)	d1	3	X1111 387214938.27	X1112 229121265.25	X1113 320012345.68		3	X1121 172095528.12	X1122 180006944.44	X1123 157760726.32		
	d2	3	X1211 172095528.12	X1212 180006944.44	X1213 254560587.61		3	X1221 180006944.44	X1222 284484444.44	X1223 229121265.25		
	d3	3	X1311 254560587.61	X1312 301464917.34	X1313 301464917.34		3	X1321 217808402.78	X1322 164694444.44	X1323 284484444.44		
$\sum X$		9	13871054.01	710593127.03	876037850.63	400502031.67	9	569910875.34	629185833.33	671366436.02	870463144.6	270965176.3
Moderate (t2) (60 °C)	d1	3	X2111 414379838.82	X2112 128880711.70	X2113 301464917.34		3	X2121 188476714.14	X2122 241338950.45	X2123 172095528.12		
	d2	3	X2211 268899262.69	X2212 268899262.69	X2213 320012345.68		3	X2221 157760726.32	X2222 217808402.78	X2223 139397377.78		
	d3	3	X2311 145145124.72	X2312 133984407.71	X2313 164694444.44		3	X2321 164694444.44	X2322 172095528.12	X2323 197558641.98		
$\sum X$		9	828424226.22	531764382.10	786171707.46	2146360315.78	9	510931884.91	631242881.34	509051547.87	1651226314.12	3797586629.91
High (t3) (100 °C)	d1	3	X3111 229121265.25	X3112 254560587.61	X3113 414379838.82		3	X3121 254560587.61	X3122 188476714.14	X3123 207313173.38		
	d2	3	X3211 145145124.72	X3212 301464917.34	X3213 301464917.34		3	X3221 284484444.44	X3222 188476714.14	X3223 188476714.14		
	d3	3	X3311 207313173.38	X3312 301464917.34	X3313 251830735.09		3	X3321 188476714.14	X3322 188476714.14	X3323 197558641.98		
$\sum X$		9	581579563.34	857490422.29	967675491.24	2406745476.88	9	727521746.20	565430142.42	593348529.49	1886300418.11	4293045894.99
Grand Total		27	139136.09	2223874843.57	2099847931.42	6953607824.33	27	126966.12	1808364506.45	1825858857.10	5407989876.93	12361597701.26

Table 5 had seven main results, which answered the seven hypotheses presented before. The discussion below is based on these results.

3.2. Discussion

The temperature did not affect the stiffness decrement of the Piper nigrum pericarp (the second row of Table 4). At a glance, this result was strange. Due to degradation temperature[52], the temperature can soften the Piper nigrum pericarp. So, why are both results different? After six days of soaking process, the Piper nigrum pericarp was soft. Besides, the Piper nigrum pericarp is very thin, around 1 mm. Hence, as soon as the Piper nigrum pericarp is soft, heating or boiling for 5 minutes will not soften the Piper nigrum. This result is because the Piper nigrum pericarp has been removed, and what is left is dominated by the hard pepper core, which is why there was no significant difference in heating the soaking water for 5 minutes.

It can be seen (the third row of Table 4) that the density did not affect the stiffness decrement of the Piper nigrum pericarp. Due to water absorption[53] of materials, It is already known that stiffness decreases with the increase in moisture content[54]. This statement is the reason why Piper nigrum farmers conduct a soaking process to soften the

Piper nigrum pericarp. Based on this finding, the lower the density, the softer the Piper nigrum pericarp. However, the density comparison among 90 gr/1 l, 90 gr/1.5 1, and 90 gr/21 are almost similar.

The sacking did not significantly decrease the stiffness of the Piper nigrum pericarp (the fourth row of Table 4). The reason is that the soaking and washing processes had caused some of the Piper nigrum pericarp to peel off before its stiffness was measured.

There was no interaction between temperature and density that affected the stiffness decrement of Piper nigrum pericarp (the fifth row of Table 4). This is due to the measurement results, which show that temperature or density had no significant effect as an independent variable.

There was no interaction between temperature and sacking in affecting the stiffness decrement of the Piper nigrum pericarp (the sixth row of Table 4). This statement is due to the measurement results, which show that temperature had no significant effect on the Piper nigrum pericarp.

There was no interaction between density and sacking in affecting the stiffness decrement of the Piper nigrum pericarp (the seventh row of Table 4). This statement is due to the measurement results, which show that density had no significant effect on the Piper nigrum pericarp.

There was a significant interaction among temperature, density, and sacking in affecting the stiffness decrement of Piper nigrum pericarp (the eighth row of Table 4).

Table 4: The stiffness measurement results

Temperature (t)	**Density (d)**	**td s1 b**	**Sacking (s_1)**				**Td s 2b**	**Not Sacking (s_2)**				**Grand Total**
			Xn			$\sum X$		**Xn**			$\sum X$	
Low (t1) (30 ° C)	d1	3	X1111	X1112	X1113	278782.85	3	X1121	X1122	X1123	153223.0788	125559.7684
			19677.78	15136.75	17888.89	52703.42		13118.52	13416.67	12560.28	39095.47	91798.8877
	d2	3	X1211	X1212	X1213	268817.83	3	X1221	X1222	X1223	139948.4346	128869.4002
			13118.52	13416.67	15954.95	42490.14		13416.67	16866.67	15136.75	45420.09	87910.2256
	d3	3	X1311	X1312	X1313	260745.52	3	X1321	X1322	X1323	134766.8556	125978.6606
			15954.95	17362.75	17362.75	50680.45		14758.33	12833.33	16866.67	44458.33	95138.7785
$\sum X$		9	48751.25	45916.16	51206.59	145874.0041	9	41293.52	43116.67	44563.70	128973.8877	274847.8918
Moderate (t2) (60 ° C)	d1	3	X2111	X2112	X2113		3	X2121	X2122	X2123		
			20356.32	11352.56	17362.75	49071.63		13728.68	15535.09	13118.52	42382.29	91453.9194
	d2	3	X2211	X2212	X2213		3	X2221	X2222	X2223		
			16398.15	16398.15	17888.89	50685.19		12560.28	14758.33	11806.67	39125.28	89810.4689
	d3	3	X2311	X2312	X2313		3	X2321	X2322	X2323		
			12047.62	11575.16	12833.33	36456.12		12833.33	13118.52	14055.56	40007.41	76463.5232
$\sum X$		9	48802.09	39325.88	48084.97	136212.9320	9	39122.30	43411.94	38980.74	121514.9795	257727.9115
High (t3) (100° C)	d1	3	X3111	X3112	X3113		3	X3121	X3122	X3123		
			15136.75	15954.95	20356.32	51448.03		15954.95	13728.68	14398.37	44082.01	95530.0400
	d2	3	X3211	X3212	X3213		3	X3221	X3222	X3223		
			12047.62	17362.75	17362.75	46773.11		16866.67	13728.68	13728.68	44324.03	91097.140354
	d3	3	X3311	X3312	X3313		3	X3321	X3322	X3323		
			14398.37	17362.75	15869.18	47630.29		13728.68	13728.68	14055.56	41512.92	89143.2146
$\sum X$		9	41582.75	50680.45	53588.24	145851.4329	9	46550.30	41186.05	42182.61	129918.9620	275770.3949
Grand Total		27	139136.09	135922.48	152879.80	427938.37	27	126966.12	127714.65	125727.05	380407.83	808346.1982

Table 5: The summary of hypotheses results with $p < 0.05$

Source	DF	The sums of squares (SS)	The mean squares (MS)	$F_{eDF:36}$	< or >	$F_{eDF:36}$	Hypothesis
Temperature (t)	2	11471776.72	5735888.36	2.085	<	19.47	Accepted
Density (d)	2	9070538.95	4535269.48	1.648	<	19.47	Accepted
Sacking (s)	1	41836152.09	41836152.09	15.205	<	250.6	Accepted
Temperature & density (td)	4	21392926.27	5348231.57	1.944	<	5.73	Accepted
Temperature & sacking (ts)	2	135368.51	67684.25	0.025	<	19.47	Accepted
Density & sacking (ds)	2	11788076.58	5894038.29	2.142	<	19.47	Accepted
Temperature, density, & sacking (tds)	4	66414163.09	16603540.77	6.034	>	5.73	Rejected
Internal (i)	36	99052104.48	2751447.35				
Total (tot)	53	261161106.70	4927568.05				

The effect of sacking was so strong that there was an interaction affecting the stiffness decrement of Piper nigrum pericarp.

Interaction is a situation where the effect of one independent variable on the dependent variable depends on the level of another independent variable[55]. In this case, the impact between two independent variables (temperature and density, temperature and density, density and sacking) was not strong enough to affect the stiffness of Piper nigrum. After the three independent variables interacted together, their impact was significant. This statement is in line with the fact that temperature, density, and density affect each other.

At a glance, almost all the above results were counterintuitive. By observing the Piper nigrum pericarps after they were soaked for six days, it was clear that many parts of the Piper nigrum pericarps peeled off. Therefore, what was measured was not solely the pericarp hardness, but rather the combination of the pericarp and seeds.

To prove the assumption of the effect of the Piper nigrum pericarps peeled off on the stiffness measurement result, a simpler experiment was conducted. The simplification method was chosen because it is not always easy to obtain good Piper nigrum samples, especially during the Piper nigrum season. Two bundles of Piper nigrum berries were tested. The one bundle comprised of fresh Piper nigrum berries. The other bundle were fresh Piper nigrum berries that were boiled for five minutes. Then the hardness of both Piper nigrum bundles was tested.

Figure 4 shows that the hardness of the boiled Piper nigrum bundle was lower than that of the one that was not boiled at all. This result is in agreement with the theory and serves as evidence that strengthens the above assumption, namely, the prolonged soaking has changed the stiffness of Piper pericarp due to the impact of the seed emergence.

Another experiment was conducted. There were three groups of Piper nigrum bundles. Each group represented a sample of low, moderate, and high density. The samples were soaked for three days.

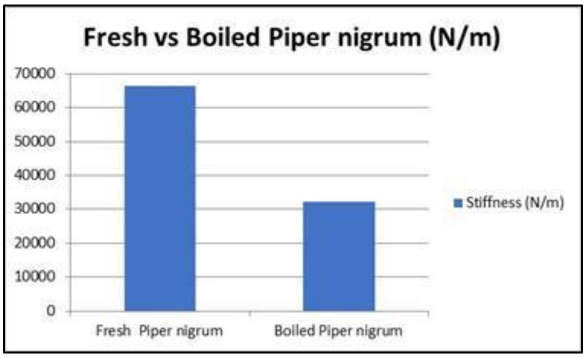


Fig. 4: The stiffness measurement results of fresh vs boiled Piper nigrum

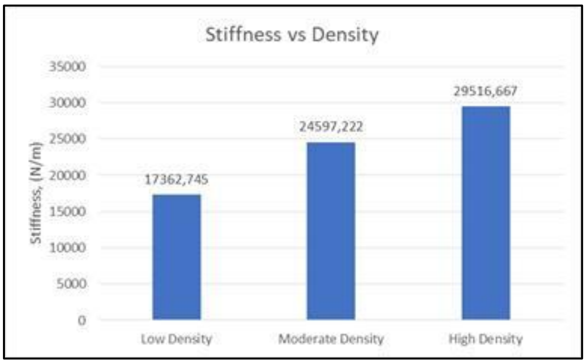


Fig. 5: The stiffness of Piper nigrum as a function of low, moderate, and high density

Figure 5 shows that the higher the density, the lower the stiffness of the Piper nigrum pericarps. This result aligns with the expected outcome.

The additional experiments yielded different results compared to the main experiment. This fact was due to many parts of the Piper nigrum pericarp being peeled off in the main experiment, whereas in the additional experiments, the Piper nigrum pericarp remained intact. In normal conditions, the interaction between two independent variables (temperature and density, temperature and sacking, and density and sacking) and among three independent variables (temperature, density, and sacking) would affect the stiffness decrement of Piper nigrum pericarp. The reality, as observed in the main experiment, did not support this claim. The more the emergence of seeds - that much harder than pericarps – the higher the measurements of the stiffness.

4. Conclusion

Based on the above discussion, two conclusions can be drawn as follows:

If the soaking has not peeled off the pericarp bundles, then the independent variables affected the stiffness measurement of Piper nigrum pericarp bundles in a regular manner, such as the higher the water temperature, the lower the stiffness measurement of Piper nigrum pericarp bundles.

In case the soaking of Piper nigrum bundles has caused some parts of the Piper nigrum pericarp to peel, the stiffness measurement of Piper nigrum pericarp bundles might give unexpected results. A lower water temperature, for example, might show lower stiffness measurements of the Piper nigrum pericarp bundles, because the measurements of pericarp bundles were unexpectedly replaced with the measurements of the pericarps and their seeds

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