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Effect of process variables on the calorific value and compressive strength of the briquettes made from high moisture *Empty Fruit Bunches* (EFB)

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Abstract. In this study, the manual hydraulic press was designed to prepare the briquettes from selected biomass waste. Each biomass was sun-dried and milled into small particle sizes before mixing with crude glycerol that used as a biomass binder. The effects of applied pressure levels of 100, 110, 120 bars, the particle size of 60, 80 and 100 mesh and the binder composition on the density, compressive strength and calorific heating value of the prepared briquettes were investigated using response surface methodology (RSM). Results showed that the briquettes have an average inside diameter, average outside diameter, and height of 12, 38, and 25-30 mm, respectively. The density of the briquettes increased with increasing the applied pressure, was in the range of 623-923 kg/m^3. The densest briquettes were obtained at 80 mesh of particle size, 53:47 binder composition ratio and 110 bars of pressurizing. The heating value of the briquette reached up to 28.99 MJ/kg obtained on the particle size of 80 mesh, 53:47 binder composition, and 110 bars and the best compressive strength of 6.991 kg/cm^2 obtained at a particle size of 100 mesh, 60:40 binder composition, and 120 bars. Process conditions influence the calorific value significantly.

1. Introduction

In the last few years, energy has become a crucial issue in the world owing to economic development, which has been accompanied by population growth, the depletion of oil reserves, and the problem of emissions from these fuels. Consumption of fossil energy is constantly increasing, which has caused the fuel crisis. Limitations in the procurement of fuel oil and gas push to thedevelopment of a renewable fuel.

Indonesia is a rich country in agricultural products, such as biomass, that could beused as the sources of renewable energy. The amount of energy from biomass is about 50,000 MW, of which only 320 MW recently used, or approximately 0.64% of the amount of existing biomass [1]. The potential

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of biomass in Indonesia includes palm oil, rice mill waste, wood, bagasse, and other agricultural waste. The land area of oil palm plantations in Riau Province in 2015, there were approximately 2.39 million hectares with the production of approximately 7.44 million tons FFB [2]. On average, one ton of FFB produces 230-250 kg of empty fruit bunches of oil palm (EFB), 130-150 kg of fiber, 60-65 shells, and 55-60 kg of seed production of oil [3]. Of the wastegenerated, only EFB has not been utilized optimally. EFB by palm processing plants is still very limited. Most of the oil factories in Indonesia are still burning EFB in the incinerator, although this has been disallowed by the Indonesian government. An alternative treatment is to hoard (open dumping), which is then used as much in oil palm plantations or processed into compost [4].

EFB waste is processed into alternative fuel, maybe through the carbonization process, which is then followed by densification. Carbonization aims to minimize the elements forming the smoke, so the exhaust gas can be cleaner [5]. Generally, biomass has poor physical properties, such as the density is quite low, storage, and transport. Densification of biomass to be briquettes aims to increase the density and reduce handling issues, such as storage and transport. In general, biomass densification has several advantages. Among the other things, it can increase in density to be stored easily and transported and have the same size and quality [6].

The calorific value of the results of briquetting could be increased by adding a binder. One of the binders that can enhanced the calorific value of the briquette is crude glycerol. Crude glycerol is a byproduct of biodiesel results that can be useful, such as cosmetic products. However, it needs further purification by high costs [7]. The idea of combining the crude glycerol waste byproduct of biodiesel production with biomass is still relatively new. Crude glycerol usehas a calorific value of 25175.98 kJ/kg, as an enhancer combustion heat values) is one of the alternatives by using glycerol without purification [8]. By this way, reducing purification costs can also be done in an integrated manner by the manufacturer of small and medium-scale biodiesel [9].

EFB has a calorific value of 19,600 kJ / kg. This value is higher than the calorific value that is possessed by palm fronds and durian skin. Accordingly, this study will use raw materials of EFB as a source of biomass briquetting and crude glycerol by-product of biodiesel as binder. The research was conducted by varying the particle size, the composition of the binder, and the pressing pressure. Based on the research of Ilham et al., (2016) [10], these conditions have a significant effect on increasing the calorific value and the compressive strength of the product briquettes produced. Optimization of data processing will be done using the response surface method (RSM). Therefore, the manufacture of solid fuel from EFB and crude glycerol is a byproduct of biodiesel production that is expected to be an alternative solid fuel because of its rich source and because it is still not optimal in its use.

2. Materials and methods

2.1 Materials

Manufacturing of solid fuels in this study used the raw materials of palm empty fruit bunches (EFB) and the glycerol by-product of biodiesel as binder. The supply of EFB was obtained from PTPN V Sei Galuh while crude glycerol was obtained from biodiesel byproduct at PT. Wilmar Bioenergy Indonesia. The equipment used consisted of hydraulic press units, a universal testing machine, and a bomb calorimeter.

2.2 Preparation of empty fruit bunches

The raw material, such as EFB, cleaned, downsized, and then dried under the sun. Furthermore, EFB carbonized in the tube furnace at a temperature of 400 °C for two hours [11]. Next, the raw carbonized product was sieved using a size 60, 80, and 100 mesh. Then, the EFB charcoal powder was mixed with crude glycerol in the ratio of 80:20; 70:30; and 60:40 and then printed by using a hydraulic press at a pressure of 100, 110 and 120 bar for 10 seconds. Briquettes were already printed and dried under the sun to reduce their water content.

2.3 Samples testing

The calorific values of the briquettes products were tested the by using the bomb calorimeter and compressive strength using a universal testing machine.

3. Results and discussion

3.1 Characteristic of EFB, carbonized and briquettes

The results regarding the EFB characteristic, carbonized EFB and briquettes is shown in Table 1.

Table 1. Characteristics of EFB, EFB charcoal, and EFB briquettes

No.	Characteristics	Unit	EFB	Carbonized product	Briquettes
1	Calorific value	kJ/kg	18,200.9	21,591.359	22,991.4 – 28,999.4
2	Water content	% - b	10.36	4.6	5.04
3	Volatile mater content	% - b	87.08	24.16	21.48
4	Dust content	% - b	1.18	0.56	0.34
5	Carbon Content	% - b	1.38	70.68	73.14
6	Compressive Strength	kg/cm^2	-	-	1.851 – 9.5316
7	Density	gr/cm^3	-	-	0.623 – 0.932

3.2 Design and analysis of results by using response surface methodology

Table 2. Summary of test results of the curvature of order 1

Responses	*p-value Prob>F*	*p-value Lack of fit*	*p-value curvature*
Calorific value	< 0.0001	0.1916	0.5480
Compressive Strength	< 0.0001	0.1329	0.1631

Based on Table 2, it can be seen that the p-value of both responses has qualified the regression test p-value smaller then $\alpha = 0.05$ and the p-value for the lack of fit responsesgreater than $\alpha = 0.05$. The models are in accordance with the data. The p-value for the curvature of each response is greater than $\alpha = 0.05$, which means there is no curvature. From the analysis of the three tests above, it can be concluded that the first-order model was appropriate because the three parameters were met.

Table 3. Summary p-value for each response

Source of variants	*Calorific value*	*Compressive strength*
Model	< 0.0001	< 0.0001
A-Particle Size	0.6904*	0.1249*
B-Filler Composition	< 0.0001	<0.0001
C-Pressing Pressure	< 0.0001	0.0034
AB	0.6476*	0.0167
AC	0.0029	0.0076
BC	0.0027	0.0010
R^2	0.9394	0.9007

Table 3 shows the component model has an influence on the response variable (Y_i). The level of probability was used $\alpha = 0.05$, and then the variable that has a p-value smaller than $\alpha = 0.05$ are variables that have a significant impact on the model. While the p-value has greater than 0.1, it does not have a significant effect on the model. The statistical analysis of the results can be used to obtain the coefficient of determination (R^2). R^2 is the amount of variability in the data obtained or calculated based on the regression model. The R^2 value is in the interval from 0 to 1. The value of $R^2$is close to 1, which indicates a high degree of correlation between the results of observation of the resulting model [12]. After all statistical tests were performed on the models, the model was obtained to study the effect of operating conditions (X_i) of the response variable (Y_i).

Testing the hypothesis on a simultaneous test was done by calculating the F_0 (F_{test}) for each response variable. The F_0value can be determined by using the ratio of the mean square regression to the mean square error, if the ratio of $F_{test} > F$ (α, DoF, DF2), H_0 is rejected.
The hypothesis applied for testing:
H_0: $\beta 1 = \beta 2 =...= \beta k$ (there is no conformity to the model)
H_1: Not all βi there is conformance in the model.

Table 4. Summary F_0 value for each variable responses (Y_i)

Responses	Sources	SS	DoF	MS	F_0	F_{table}
Calorific Value	Regression	4.781E+007	7	6.830E+006	24.37	3.01
	Error	3.084E+006	11	2.803E+005		
	Total	5.100E+007	19			
Compressive Strength	Regression	52.57	7	7.51	14.25	
	Error	5.80	11	0.53		
	Total	59.55	19			

The F_{table} value is F (α, DoF, DF2) with a probability level of $\alpha = 0.05$ with the DoF being a degree of freedom. The F_{table} value for distribution of F (0.05,7,11) is 3.01. Therefore, if the result of F_0>F (α, DoF, DF2) and $H_0$is rejected, suggesting that the model is used significantly affectsthe responses. After all statistical tests are performed on the model, the model was obtained to study the effect of operating conditions (X_i) of the response variable (Y_i).

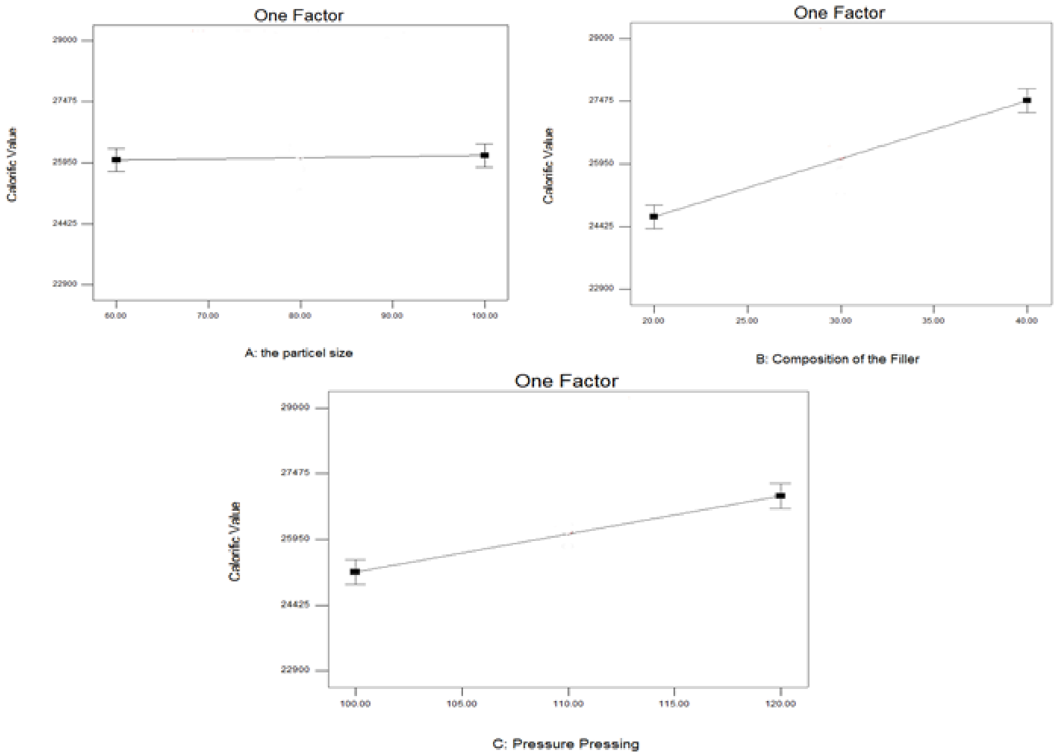

Figure 1. Effect of process conditions on the calorific value: a) The size of the particles; b) The composition of the filler; c) Pressure pressing

3.3 Analysis response calorific value

Figure 1 shows that the composition of the filler and the pressing pressure havea significant effect on the value of the heat produced because it can increase the calorific value of the briquettes. In this study, the raw material EFB has a calorific value of 18200.975 kJ / kg. The calorific value of briquettes produced by the densification process ranged from 22991.4 to 28999.4 kJ / kg. The addition of filler in the form of crude glycerol significantly increases the calorific value by 62.76% of the calorific value of the raw material. This is consistent with the results obtained by Asavatesanupap and Santikunaporn (2012) [7], which states that the addition of crude glycerol can improve the calorific value.

Stamping pressure also influences the calorific value of the briquettes. The greater the pressure, the density of the briquette presses becomes bigger so more charcoal gets in contact with the filler in the form of crude glycerol toincrease the calorific value [13]. In addition to the filler's composition, and the pressing pressure having a significant effect, the particle size does not affect the calorific value of the briquettes. This is evident from the p-value of the particle size of 0.6904. The p-value for the variable particle size exceeds the probability value is> $\alpha = 0.05$, so it can be concluded that the particle size does not provide a significant effect on the calorific value.

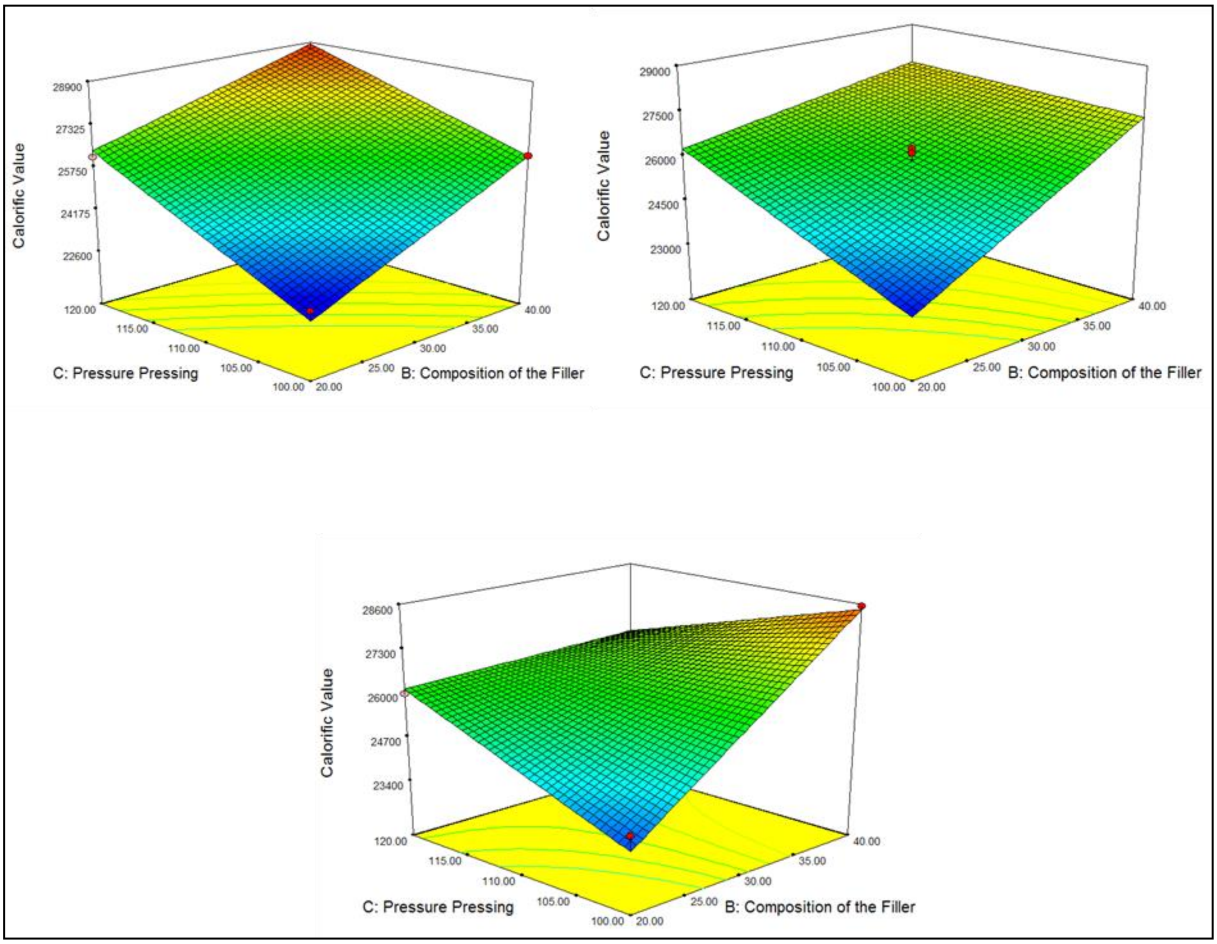

Figure 2. Effect of particle size on calorific value.

Based on data from the ANOVA test, Figure 2 shows that the filler composition and pressing pressure havea significant effect on increasing the calorific value. The more filler used and if the pressing pressure is great, then the value of the heat produced will be higher. This is consistent with that presented by Saktiawan (2008) [13], Ali et al., (2012) [9] and Asavatesanupap and Santikunaporn (2012) [7] that the composition of the filler and the pressing pressure can improve the calorific value.

3.4 Response analysis on compressive strength

Figure 3 indicates that the composition of the filler and the pressing pressure significantly influence compressive strength. From the p-value of the composition of the filler and the pressing pressure in Table 3.5, the more filler used, the compressive strength also increases. Likewise, if the pressing pressure is large, the pressure pressing densities and compressive strength will also be increased. The effects of particle size are not very significant, because of the p-value of the particle size in Table 3. The compressive strength of the briquettes produced ranges from 1.851 to 9.5316 kg/cm^2. The best compressive strength of 6.991 kg/cm^2 was obtained at a particle size of 100 mesh, 60:40 filler composition, and a pressing pressure of 120 bar.

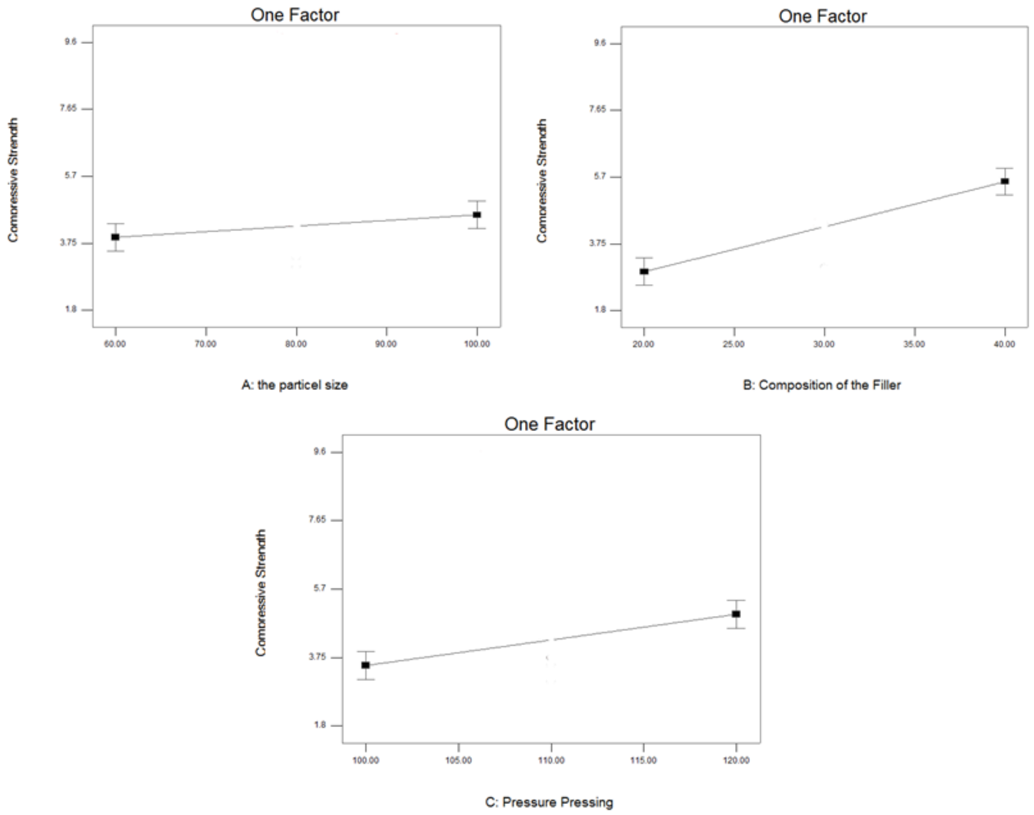

Figure 3. Effect of compressive strength of process conditions a) particle size b) the composition of the filler c) pressure pressing.

Figure 4 shows that the interaction between the filler composition and the pressing pressure has a significant influence on the compressive strength. The relationship between the composition of the filler and the pressing pressure is directly proportional to the compressive strength. The greater the pressure exerted when the densification process accompanied by the composition of the filler increasesthe compressive strength. The purpose of the pressing pressure is to producethe contact between the surfaces of the charcoal with crude glycerol as filler, so the briquettes are not easily broken [14].

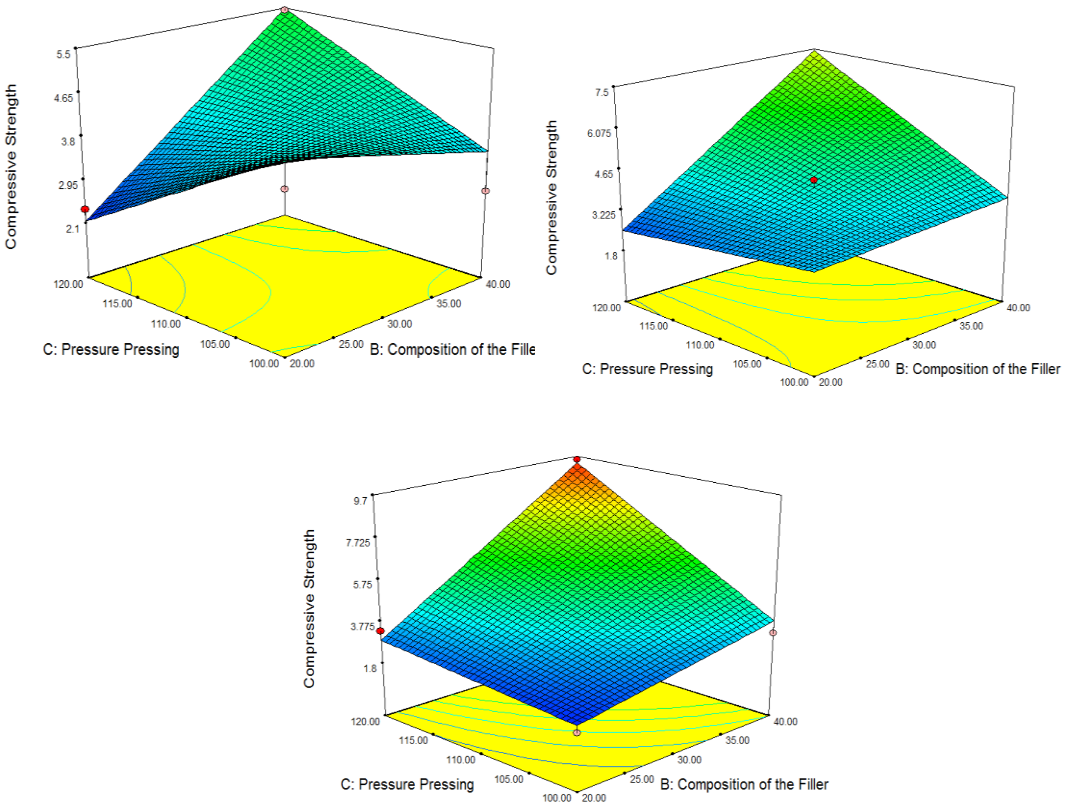

Figure 4. Effect of particle size on compressive strength.

3.5 Density of the briquette

The density of the briquettes produced in this study amounted to 0.623 to 0.932 g / cm^3. The density value greatly affects the quality of the briquettes. Therefore, if the density is large, the quality of the briquettes will be high. The density of the briquettes is affected by the composition of filler, particle size, and pressure pressing. The best density is 932 kg/cm^3obtained onaparticle size of 80 mesh, 53:47 filler composition, and pressure of 110 bar.

4. Conclusions

The composition of filler and pressure of pressing have a significant influence on the response of the calorific value and compressive strength. The best calorific value of 28999.4 kJ/kg was obtained on the particle size of 80 mesh, 53:47 filler composition, and the pressing pressure of 110 bar. The best compressive strength of 6.991 kg/$cm^2$was obtained at a particle size of 100 mesh, 60:40 filler composition, and a pressing pressure of 120 bar.

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