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ORIGINAL ARTICLE

The Significant Process Variable of High-Density Tea Powder Production in Spray-Dry Method

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ABSTRACT – Polyphenol, which is very beneficial to the human body, especially as an obesity inhibitor, is one of the leading nutrient content in green tea leaves. To increase popularity and practicability, product development needs to be conducted, one of which is to produce an effervescent instant tea. However, a high-density instant tea powder is required in this product development. This study was conducted to predict the significant process variables that affect the density and yield of the instant tea powder. The exploration of significant process variables was conducted based on the Design of the Experiment, while the tea extract was produced using maceration techniques. Maltodextrin was added to the tea extract based on the concentration filler variable. The instant tea powder was produced by the spray drying method, which variable includes the concentration of maltodextrin (Filler), the feed pump flow rate (RPM), the outlet temperature (T_{out}), the hot air flow rate (Fan), and the atomization air pressure (Nozzle). The tapped density of the instant tea powder was analyzed, and the yield was calculated for each condition. Based on the Pareto graph, it was found that the atomization air pressure (Nozzle) is the most significant variable in the spray dry process of instant tea powder.

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INTRODUCTION

Obesity and overweight have become a global public health problem in recent years. World Health Organization (WHO) stated that obesity in the European region in May 2022 reached 60% [1]. In 2013, the WHO also reported that obesity was the fifth leading risk of death globally [2]. A commercially available anti-obesity drug is a gastrointestinal lipase inhibitor known as orlistat. Orlistat inhibits fat absorption by inhibiting the lipase enzyme that breaks down fat. However, consumption of orlistat has side effects, including oily stools, farting with discharge, and sudden intestinal irritation [3]. Therefore, an alternative is needed, one of which is consuming green tea-based functional beverages.

Green tea (*Camellia sinensis*) has been widely consumed worldwide for thousands of years. Green tea is produced by heating fresh tea leaves to prevent the enzymatic oxidation of catechin compounds. Dried green tea leaves contain 15–30% catechin compounds consisting of 59.04% Epigallocatechin gallate (EGCG), 19.28% Epigallocatechin (EGC), 13.69% Epicatechin gallate (ECG), 6.39% Epicatechin (EC), and 1.60% Gallocatechin (GC) [4]. The main catechins in green tea, (-)-epigallocatechin-3-gallate (EGCG), are believed to have anticancer, antiviral, and neuroprotective activities [5].

Green tea extract was reported to reduce visceral adipose tissue and lower triglyceride levels in diet-induced obese zebrafish animals [6]. Another study on epidemiological analysis found that individuals who regularly consume green tea do not experience obesity conditions [7]. A study reported that EGCG can reduce body weight by about 3 kg, abdominal circumference by 3.3 cm, and 2.5 kg of body fat in 12 weeks [8]. However, conventional green tea still has disadvantages regarding the practicality of consumption.

In addition, green tea preparations are generally put into porous bags (tea bags). Health issues regarding the chlorine content of the bag have led to a decrease in the consumption of tea. In addition, one teabag is known to release 11.6 billion microplastic particles into the brewing water [9]. Microplastics contain harmful compounds, polychlorinated biphenyls (PCBs), metals, and polybrominated diphenyl ethers (PBDEs) due to their accumulation in the human body [10]. To overcome this problem, an innovation was developed in the form of powdered green tea extract, which is more practical and easy to consume and has a very high content of active catechin compounds compared to bulk green tea.

One of the powder production processes is the spray dry technology. Spray dryer is widely applied in the industrial field due to its capability to produce excellent powder quality. The liquid was sprayed through the nozzle, which generated fine droplets, and then contacted with the hot air in the drying chamber. The drying process occurred as the droplet moved down to the bottom of the drying chamber and produced a fine powder. The powder is then separated

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from the hot air based on the centrifugal force in the cyclone to be collected in the product pot [11]. The green tea product was fine as a final product. However, the tea instant is the derived product of the green tea product, where the added value is incorporated. To get the desired product properties, i.e., yield and density, some significant variables in the spray dry process need to be predicted.

The objective of this study is to predict the significant process variables that affect the density and yield of instant tea powder. The variables include the concentration of maltodextrin (Filler), the feed pump flow rate (RPM), the outlet temperature (T_{out}), the hot air flow rate (Fan), and the atomization air pressure (Nozzle). The exploration of significant process variables was conducted based on the Design of the Experiment.

EXPERIMENTAL METHOD

The material, including the green tea leaves and the maltodextrin, was from the Research Center for Chemistry (National Research and Innovation Agency, BRIN) and the Indonesia Research Institute for Tea and Cinchona Gambung, respectively. The spray dryer and the tapper for the density method were provided by the Research Center for Chemistry, BRIN.

Green tea

The dried copped green tea leaves were obtained from the Indonesia Research Institute for Tea and Cinchona Gambung. The tea was a Gamboeng-specific clone containing high polyphenols and was harvested in August 2023.

The Extraction Process of the Tea Leaves

The tea extraction was conducted via a common maceration process using 300 g of dried copped green tea leaves and 2000 g of boiled water at 90°C. The tea was stirred and then settled for 1 hour before being filtered using a cloth filter. The solid content was analyzed based on the gravimetric method, resulting in a solid content of 4.59%.

Maltodextrin was added to the tea extract as the filler. The amount of maltodextrin was 15% and 25% based on the weight of the tea extract, depending on the experiment variable.

Spray Drying Process of the Tea Extract

The tea extract was dried using a spray drying apparatus. The spray dry device used in this study was Ohkawara Kakohki type NL-3 operated in an “open” operation mode. It has a twin jet series as the nozzle type with adjustable atomization air pressure set depending on the variable. The tea extract was pumped using a peristaltic pump at various speeds, which are 10 and 20 RPM, corresponding to 9 and 18 ml/min, respectively. The outlet temperature and the hot air flow rate (Fan speed) were set based on the variable. Meanwhile, the inlet temperature was recorded, and the outlet temperature was maintained. Figure 1 presents the spray dry apparatus used in the current study. The outlet temperature can be controlled by changing the inlet temperature if the feed rate, fan speed, and atomization air pressure are defined and maintained constant. Hence, the effect of each variable can be observed if it is changed.

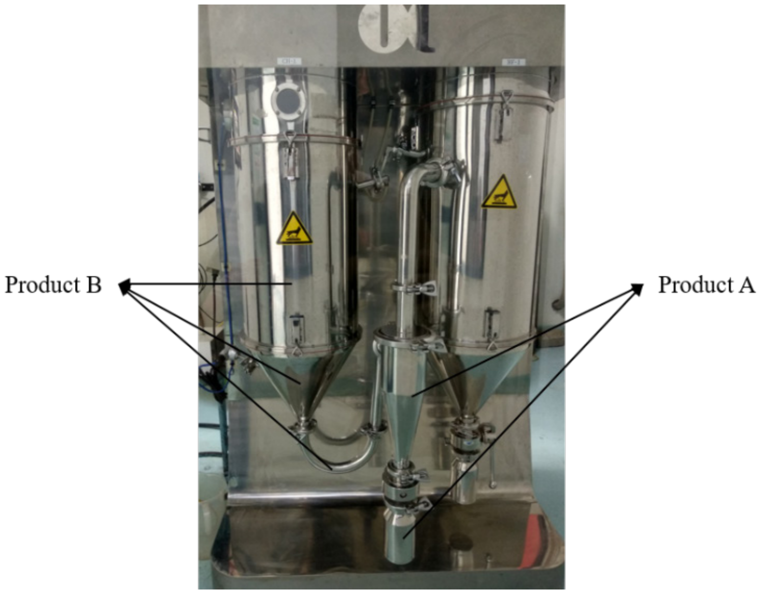


Figure 1. The spray dry apparatus used in the current study in the Research Center for Chemistry, BRIN.

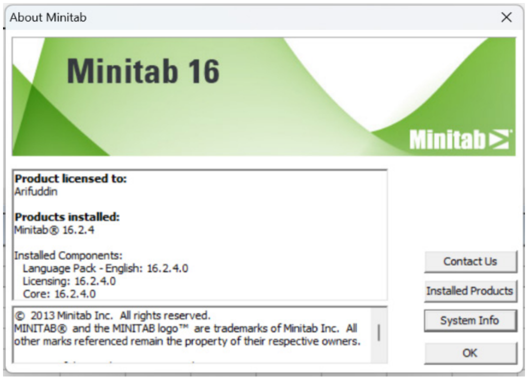
Referring to Figure 1, the product can be classified as "Product A" and "Product B" based on the product's location. Product A was collected from the cyclone and the product pod, while Product B was collected from the drying chamber, cone, and pipeline before the cyclone.

The atomization air pressure in the spray dryer is different from the drying air in circulation. The atomization air is compressed air from a compressor unit at ambient room temperature (around 23°C), which only affects the droplet size by the nozzle in a spry-dry system. The higher the atomization air pressure, the smaller the droplet produced by the nozzle [12]. However, this relation depends on other variables, such as the density of the liquid and the crystallinity properties of the solid content [13], which are out of the scope of this manuscript. At the same time, the drying air is circulated heated air to dry the droplet produced by the nozzle.

The Design of Experiment

To simplify the study, the design of the experiment was created using Minitab® software. The version and details of Minitab® software can be seen in Table 1.

Table 1. Minitab® software version details

Minitab® version details	Screenshot of Minitab® details
Products installed: Minitab® 16.2.4 Installed Components: Language Pack-English: 16.2.4.0 Licensing: 16.2.4.0 Core: 16.2.4.0	

For screening purposes, the factorial design was applied using the Plackett-Burman design. Based on the description in the previous section, it can be concluded that the factor variables in the current study are the concentration of maltodextrin (Filler), the feed pump flow rate (feed pump-RPM), the outlet temperature (T_{out}), the fan speed representing the hot air flow rate (Fan), and the atomization air pressure (Nozzle). Hence, the factor of the Plackett-Burman design was set as five factors with 12 runs. Table 2 presents the design of the experiment for the current study. The responses for the variable will be the yield and the tapped density of the instant tea product.

Table 2. Design of Experiment using factorial Plackett-Burman design five factors for 12 runs

StdOrder	RunOrder	Feed pump (RPM)	Tout (°C)	Nozzle (kPa)	Fan (Hz)	Filler (%) w/w
9	1	10	60	60	36	25
5	2	20	70	60	36	25
12	3	10	60	60	28	15
11	4	10	70	60	28	15
7	5	10	70	180	36	15
6	6	20	70	180	28	25
3	7	10	70	180	28	25
8	8	10	60	180	36	25
2	9	20	70	60	36	15
10	10	20	60	60	28	25
1	11	20	60	180	28	15
4	12	20	60	180	36	15

The Instant Tea Yield Analysis

The instant tea yield analysis was based on the total solid content of the tea extract, which was calculated with Equation (1).

$$TS\ (g) = 4.59\% \times Tea\ extract\ (g) + Filler\ (g) \tag{1}$$

The instant tea yield was calculated using the formula in Equation (2).

$$Instant\ tea\ yield\ (\%) = \frac{Mass\ of\ instant\ tea\ collected\ (g)}{TS\ (g)} \times 100\% \tag{2}$$

The instant tea yield was calculated based on Product A and Product B, while the total yield was a summary of both yields.

Density Analysis

The density analysis was based on the tapped density method using Copley JV-1000. The bulk density was analyzed by weighing 20 g of the sample into a measuring glass. The volume, which was occupied by the sample, was defined as the bulk volume. Then, the measuring glass was tapped 1250 times or when the volume remained constant (the difference is less than 2%) [14], [15]. The volume is reduced after tapped and defined as the tapped volume. The tapped density was calculated based on Equation (3).

$$Tapped\ density\ \left({}^{g}/_{ml}\right) = \frac{Instant\ tea\ sample\ \ (g)}{Tapped\ volume\ (ml)} \tag{3}$$

RESULT AND DISCUSSION

Table 3 presents the mass and density of Product A and Product B based on the Design of Experiment order. Based on the data in this table, the yield calculation of each product (Product A and Product B) was conducted.

Table 3. Mass and density of Product A and Product B based on the Design of Experiment variable

RunOrder	Total Solid	Product A	Product B	Total Product	Yield of Product		Density of Product	
	(g)	(g)	(g)	(g)	A (%)	B (%)	A (g/ml)	B (g/ml)
1	443	181.2261	209.669	390.8951	40.9088	47.3293	0.4412	0.5770
2	400	113.1328	109.6442	222.7770	28.2832	27.4111	0.4444	0.6667
3	261	111.242	55.1931	166.4351	42.6215	21.1468	0.4762	0.5405
4	252	120.4192	100.68	221.0992	47.7854	39.9524	0.3774	0.5000
5	240	165.466	22.6524	188.1184	68.9442	9.4385	0.3922	0.3390
6	378	186.0516	85.7481	271.7997	49.2200	22.6847	0.4348	0.3704
7	389	191.1688	82.4868	273.6556	49.1437	21.2048	0.3704	0.4000
8	391	142.755	107.4308	250.1858	36.5102	27.4759	0.4545	0.4878
9	291	99.0295	123.4607	222.4902	34.0308	42.4264	0.4615	0.6123
10	409	78.0911	26.5026	104.5937	19.0932	6.4799	0.4255	0.7143
11	262	121.4079	88.5455	209.9534	46.3389	33.7960	0.4348	0.4444
12	248	145.6681	60.3996	206.0677	58.7371	24.3547	0.4651	0.4651

The analysis of variance (ANOVA) was conducted based on Minitab® using the data from Table 2 and Table 3. The result was presented as a Pareto diagram of yield and density in Figure 2 and Figure 3 for Product A and Product B, respectively.

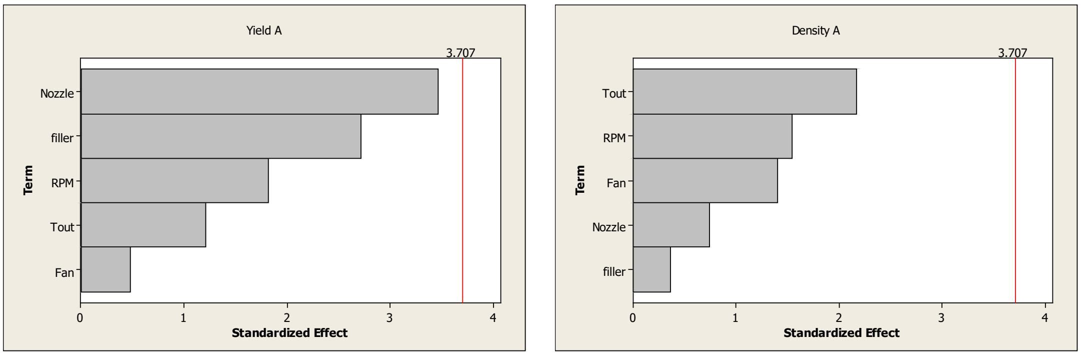


Figure 2. Pareto chart of the standardized effects of yield and density of Product A

Based on Figure 2, it can be seen that all standardized effects do not pass the threshold line, where the effect is 3.707 on both the yield and density Pareto graph. This indicates that there is no significant factor in both the yield and density of Product A. In other words, the significant factor that affects the yield and the density of Product A cannot be predicted by the suggested model.

However, based on the rank of the factors, it can be stated that the atomization air pressure (nozzle), the concentration of maltodextrin (filler), and the feed pump flow rate (RPM) are the top 3 most significant factors for yield of Product A. In addition, based on the rank of the factors, it can be stated that the top 3 most significant factors for the density of Product A are the outlet temperature (Tout), the feed pump flow rate (RPM), and the fan speed. The feed pump flow rate (RPM) is suggested to be the significant variable affecting Product A in yield and density because it is included in the top three variables of both yield and density of Product A.

Moreover, the yield and the density of Product A can be predicted based on Equation (4) and Equation (5), respectively. The equations can be seen as follows.

$$\text{Yield A} = -0.8415A + 0.5575B + 0.133597C + 0.276875D - 1.25517E + 20.0625 \quad (4)$$

$$\text{Density A} = 0.00257A - 0.00361B + 0.0029125D + 0.558933 \quad (5)$$

A, B, C, D, and E are RPM, Tout, Nozzle, Fan, and Filler, respectively. Based on Equation (4), it can be concluded that RPM and Filler negatively affect the yield of product A. In other words, the higher the feed flow rate (RPM) and the filler concentration (filler), the lower the yield. On the contrary, the other variables, i.e., Tout, Nozzle, and Fan, affect the yield positively, where the yield increases as the variable increases. This phenomenon is in good agreement with the previous study, which stated that the Tout was in positive relation to the product yield [16]–[18]. However, some studies state that Tout has a negative relation to the product yield [19]–[21]. This contentious result was due to the natural properties of both the raw and the carrier material as well as the process condition applied [22], [23].

Moreover, based on Equation (5), it can be observed that the Tout negatively affects the density of product A, while the increase of the feed pump flow rate (RPM) and the hot air flow rate (Fan) will increase the density as well. However, the Nozzle and Filler were considered to have very little effect on density that the coefficient is almost zero. Hence, they are neglected in Equation (5).

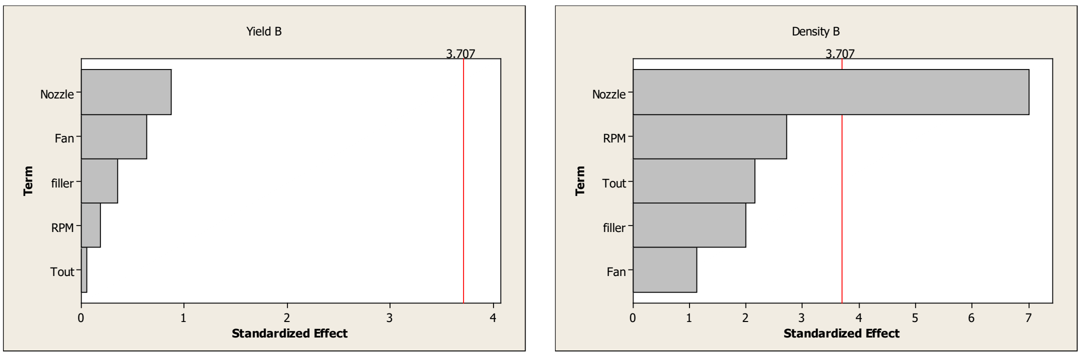


Figure 3. Pareto chart of the standardized effects of yield and density of Product B

Based on Figure 3, the nozzle pressure is the most significant factor affecting the density of Product B. On the other hand, the most significant factor affecting the yield of product B cannot be predicted by the suggested model because the standardized effect of each factor in the Pareto graph is less than the threshold.

However, based on the rank of the factors, the atomization air pressure (Nozzle), the hot air flow rate (Fan), and the concentration of the filler (Filler) are the top 3 most significant factors for the yield of Product B, while the feed pump flow rate (RPM) and the outlet temperature (T_{out}) are included as the top 3 most significant factors that affect the density of Product B, beside the atomization air pressure (Nozzle).

Moreover, the yield and the density of Product A can be predicted based on Equation (6) and Equation (7), respectively. The equations can be seen as follows.

$$\text{Yield B} = -0.1585A + 0.0435B - 0.0636806C + 0.69146D - 0.3085E + 18.2008 \quad (6)$$

$$\text{Bensity B} = 0.03574A - 0.02839B - 0.09201C + 0.01486D + 0.02624E + 0.50979 \quad (7)$$

where A, B, C, D, and E are RPM, T_{out}, Nozzle, Fan, and Filler, respectively. According to Equation (6), it can be seen that T_{out} and Fan have a positive effect on the yield of Product B, which will increase if the T_{out} and the Fan increase. This is the same relation to the yield of Product A. On the other hand, the yield of product B has a negative relation to RPM, Nozzle, and Filler. In other words, to increase the yield of Product B, the feed pump flow rate (RPM), the atomization air pressure (Nozzle), and the concentration of filler (Filler) should be decreased.

Moreover, based on Equation (7), it can be observed that the RPM, the Fan, and the Filler have a positive relation to the density of Product B, while the T_{out} and Nozzle have a negative relation to the density of Product B. Almost all variables resulted in the same effect on the density of Product B as in Product A. However, in Product A, the nozzle and filler have an insignificant effect that is neglected, while in Product B, it is both in negative and positive relation to the density, respectively. Previous studies have also reported this phenomenon. The consecration of filler can be in positive relation [17], [19], [22] or with no relation to the product density [24]. However, some contradictive results were also reported, where the concentration had a negative relation to the product density [25].

Finally, based on this analysis, it can be concluded that the most significant variable in the density of Product B is the atomization air pressure (nozzle). Moreover, there were some contradictive results regarding the relation of some variables to both the product yield and the product density.

CONCLUSION

An experiment was carried out to predict the significant variables in the spray drying process for the production of instant tea powder. The variables included maltodextrin concentration (Filler), the feed pump flow rate (RPM), outlet temperature (T_{out}), the hot air flow rate (Fan), and atomizing air pressure (Nozzle). The density and yield were used as inputs in the analysis of variance (ANOVA), where a Pareto chart was produced as the result, and a predictive equation was derived.

Based on the Pareto chart, the significant variable can be predicted only for the density of Product B. Unfortunately, the model suggested by Minitab® cannot predict the significant variables for other parameters, i.e., the yield of Product A, the density of Product A, and the yield of Product B, due to the low standardized effect value of each variable. However, the top three variables that affect the parameter can be predicted based on the rank in the Pareto graph. Based on the rank in the Pareto chart, the feed pump flow rate (RPM) and the atomization air pressure (Nozzle) are suggested to be the significant variable that affects both the yield and the density of Product A and Product B, respectively.

Moreover, some relation between the variable and the response has been discussed. The RPM and Filler negatively affect the yield of Product A, while the T_{out}, Nozzle, and Fan affect the yield of Product A positively. Moreover, the T_{out} negatively affects the density of Product A, while RPM and Fan affect the density of Product A positively. In addition, T_{out} and Fan have a positive effect on the yield of Product B; on the contrary, the yield of Product B has a negative relation to RPM, Nozzle, and Filler. The RPM, the Fan, and the Filler have a positive relation to the density of Product B, while the T_{out} and Nozzle have a negative relation to the density of Product B. Some of this relation was also observed in the other studies.

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