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Hydrodynamic study of drying on Qisthi Hindi using a Fluidized Bed Dryer

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Abstract
A Fluidized Bed Dryer (FBD) is one of the most efficient and prominent moisture-reducing dryers in the food, chemical, and pharmaceutical industries. This work investigates changes in moisture content and drying rate in the FBD with a dense bed as a perforated plate and uses an indirect heating medium. Here the air flows by the blower and acts as a dryer after passing through the heater to reduce the moisture content contained in the material. Qisthi Hindi can be used as herbal medicine for several diseases such as asthma, cough, diabetes, and liver and stomach problems. It can even be consumed during the COVID-19 pandemic. The Qisthi Hindi root has a fairly high calcium and protein content, so drying must be carried out at moderate temperatures because it is a heat-sensitive material. Drying using FBD is carried out at temperatures ranging from 50-100 °C. On air drying at 50 °C, the protein content increased by 3.13%, calcium content increased by 29% from the levels before drying, and water content decreased by 5.3%. At the drying air temperature of 100 °C, the protein content decreased to 3.87%, and the calcium content decreased by 15% from drying at 50 °C. FBD reduced the moisture content significantly in Qisthi Hindi, which is heat sensitive.

Keywords:
Drying;
Fluidized Bed Dryer;
Hydrodynamics;
Qisthi Hindi;

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INTRODUCTION

Drying is a way to remove or remove some of the water from a food material by evaporating some of the water contained in the food using heat energy [1]. The drying process causes changes in the texture, color, and aroma of foodstuffs and causes the substances contained in foods, such as proteins, fats, carbohydrates and minerals, to be more concentrated [2]. A Fluidized Bed Dryer (FBD) is a drying process that utilises hot air flow at a certain speed passed through the material bed so that the material has fluid-like properties [3]. This drying aims to reduce the water content of the material to inhibit the development of spoilage organisms. The water content of a material affects the amount of water that is evaporated and the length of the drying process [4][5]. Dry air acts as a solvent to extract solutes, i.e. water content from wet materials [6]. Most of the drying process is focused only on the hydrodynamic level, including particle separation [7] so monitoring the moisture and hydrodynamics of the granules during drying is important to ensure the quality of the final product [8]. The water content in materials, especially agricultural products, is divided into three conditions: water contained in free water conditions, water contained in a bound state (bound water), and water contained on the surface of the material (hydration water). The use of drying with the FBD model for granular materials has been widely used in food and chemical processing [9, 10, 11]. FBD is commonly used in the pharmaceutical and food industries to remove water content in materials by continuously flowing hot air to force mass transfer [12, 13, 14, 15, 16, 17]. FBD provide good solids mixing, high heat and mass transfer rates and relatively easy handling [18]. FBD is one of the prominent moisture-removing dryers in the industry [19]. FBD is widely used in the food and chemical industries to dry wet particles quickly and effectively [20]. (FBD) is important for preserving agricultural products and is commercially applied for drying processes and engineering applications [21]. In this study, Qisthi Al Hindi root was used as the material to be dried. This plant, as herbal medicine, is used for several diseases such as asthma, cough, diabetes, and liver and gastric problems [22]. It can even be consumed for endurance during the COVID-19 pandemic. The drying process causes changes in the texture, color, and aroma of foodstuffs and causes the substances contained in foodstuffs, such as proteins, fats, carbohydrates and minerals, to be more concentrated [23][24]. FBD has several advantages, such as faster drying, lower energy consumption and uniform water content [25].

Based on the above background, the author feels the need to research the calcium content in the roots of Qishti Hindi so that it can be utilized for the wider community's needs. This activity was carried out experimentally using drying with an FBD, and this is the first study conducted to determine the calcium content in the roots of Qisthi Hindi. To prove the hypothesis that the drying air temperature in the drying process of Qisthi Hindi roots affects the damage that occurs to the calcium contained in the roots of Qisthi Hindi. Calcium is one of the main mineral content that is needed by the body in the process of forming enzymes, bones and teeth, and low calcium intake can result in low mineralization of new bone deposit matrix and osteoblast dysfunction [26]. The hormonal system regulates the balance of calcium in the bones and blood. Calcium can be found in everyday foods such as green vegetables, dairy and dairy products, seafood, nuts and seeds, and calcium-fortified foods such as cereals, slices of bread and oatmeal.

The need for calcium per day according to the Regulation of the Minister of Health of the Republic of Indonesia No. 28 of 2019 is 1000 mg for children aged 4-9 years, 1200 mg at the age of 10-18 years, 1000 mg at the age of 19-49 years and 1200 mg at the age of 50-80 years. Qisthi Hindi or Indian costus or Saussurea costus is a member of the Asteraceae family of flowering plants. This plant has a height of about 1.5–2 meters. The roots of this plant can reach 60 cm and can be used by humans. Utilization of this plant, as herbal medicine, is used for several types of diseases such as asthma, cough, diabetes, and liver and gastric problems. Qisthi Hindi grows at 2600-4000 masl [27]. In Qisthi Hindi root, several ingredients are often used: terpenes, flavonoids, anthraquinones, alkaloids, tannins and inulin [28]. Qisthi Hindi root contains several compositions of energy values needed by the body, as in Table 1. Table 1 shows that the calcium value in Qisthi Hindi roots can be classified as having a high value and when compared to other tubers as shown in Table 2. In addition, Table 2 shows that the value of calcium, protein, total energy, and carbohydrates in Qisthi Hindi roots is higher than in potato, cassava and taro. The tool used in this research is an FBD with testing materials using Qisthi Hindi roots.

Table 1. Test Result Report: SIG.LHP.III.2021.038075

Parameter	Unit	Result	Method
Vitamin E	mg/100g	0.75	18-5-1/MU/SMM-SIG (HPLC)
Calcium	mg/100g	378.63	18-13-1/MU/SMM-SIG (ICP-OES
Protein	%	6.72	18-8-31/MU/SMM-SIG (Kjeltec)
Ash Rate	%	4.91	SNI 01-2891-1992, 6.1
Energy from fat	kcal/100g	11.52	Calculation
Total fat	%	1.28	18-8-5/MU/SMM-SIG point 3.2.2 (Weibull)
Water content	%	8.54	SNI 01-2891-1992, point 5.1
Total energy	kcal/100g	352.6	Calculation
Carbohydrate	%	78.55	18-8-9/MU/SMM-SIG

Table 2. Comparison of Qisthi Hindi Parameters with Grains, Tubers and Roots

Parameter	Type of Materials			
	Qisthi Hindi*	Potato	Cassava	Taro
Calcium (mg/100g)	378.63	11	33	28
Protein (gr)	6.72	2.0	1.2	1.9
Water content (gr)	8.54	77.8	62.5	73
Total energy (Kal)	352600	85	146	104
Carbohydrate (gr)	78.55	19.1	34.7	23.7

Source: 1. SIG Lab Results*. 2. Faculty of Medicine, Indonesia University

METHOD

Fluidization is a phenomenon caused by the treatment of fluids (liquids or gases) on solids so that solids will act as liquids or gases. In the case of drying materials using FBD, the solids are particles of the material, while the fluid is air. The working principle of this tool is that there is an event of hot air blowing by a blower fan through a channel to the dryer. In the mechanical drying process, the air carries heat into the drying chamber to evaporate the water contained in the material. It then carries the water out of the drying chamber. The FBD specifications used are listed in Table 3. The flow diagram of the FBD system can be seen in Figure 1.

The data collection process in this experiment was started by preparing the FBD dryer and Qisthi Hindi root material. Then, the process is continued by performing a function test on the dryer to ensure all components are functioning properly. After everything is functioning properly, the dryer is tested without materials to determine the residence time from the start of the appliance being turned on until it reaches the desired temperature with the help of the temperature switch control. When the tool reaches the desired temperature, the material is put into a drying bed and dried until the temperature of the material reaches 50 °C. The same process was repeated in the second test material at 100 °C. The ideal temperature for drying heat-sensitive materials is between 50-80 °C [29][30].

Table 3. FBD Specification

Description	Specification
Blower motor	200 Watt
Blower flow	570^3/minute
Blower blade thickness	1 mm
Cyclone tank	None
Drying tank material	SUS and Aluminum
Function	Drying and Roasting
Condenser	750 Watt
Electric coil heater	700 Watt
Temperature gauge	Digital type
Heater	Up to 300 °C

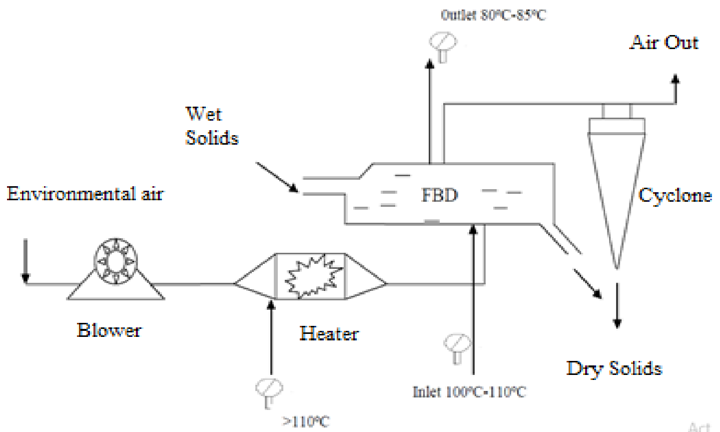

Figure 1. Drying Process Flow Diagram on FBD

After the drying test process with the FBD, the material is vacuumed and delivered to the laboratory to be tested for the content contained after drying. The test results are obtained based on the materials' specifications, such as the starting material's water content and the material's mass before being tested. The Qisthi Hindi root user has an initial weight of 1 kilogram. Materials are divided into three laboratory tests, namely testing raw materials, testing after drying at a temperature of 50 °C and testing after drying at a temperature of 100 °C. The average weight used in laboratory testing is 300 grams. The raw material during the first test was still in the form of roots, while in the test, during drying with the FBD the material was chopped to facilitate the evaporation process. The test results on raw materials obtained the calcium value contained in Qisthi Hindi of 378.63 mg/gram. Calculations are made after the material is inserted into the drying bed for 30 minutes.

RESULTS AND DISCUSSION

The characteristics of the FBD are determined in three core parts: the blower, heater and dryer room. Characteristics of an FBD include heat transfer energy in the form of enthalpy energy produced to dry material. Other factors that affect the drying of material include Dry Bulb Temperature (DB), Wet Bulb Temperature (WB), Dew Point Temperature (DP), Specific Humidity (W), Relative Humidity (RH) and Specific Volume (RH).

Dry bulb temperature is the temperature that is read on a thermometer in open-air conditions. The temperature of the dry ball indicates the sensible heat, whereas the change in the temperature of the dry ball also results in a change in sensible heat. Wet bulb temperature is the temperature read on a thermometer with a sensor wrapped in a wet cloth to remove heat radiation. Dew Point Temperature is the air temperature at saturation or the temperature at which water vapour begins to condense when the mixture of air and water vapour is cooled. In saturation conditions, the temperature of the dew point is equal to the temperature of the wet ball and the dry ball. The dew point temperature indicates the latent heat that occurs because any change in the dew point temperature results in latent heat. Specific Humidity or humidity comparison can also be referred to as the Humidity Ratio, where it can be defined as the mass of water vapour contained in 1 kg of dry air. The relative humidity is the ratio between the temperature pressure of water vapour in the air to the saturation pressure of water vapour at the same dry ball temperature. Specific volume is a mixture of air and water vapour or moist air every 1 kg of dry air. The characteristics of the three components of FBD are listed in Table 4.

The data will be obtained by calculating power, air discharge, Enthalpy and flow rate that occurs in the drying process with that temperature. Based on the data known efficiency of the blower is 85%, then obtained the following data: Q = 5.4362074258 m^3/s and h_u = 45883.94 kJ/Kg.

Table 4. Characteristics of Enthalpy Blower on FBD

Efficiency	**Power**	**air time flow rate**		**airflow discharge**	**Ambient temperature of the air**			**Dew point temperature**
η	P			Q	Db	Wb	RH	Tdp
%	Watt	rpm	Kg/s	m^3/s	°C	°C	%	˚C
0.85	186.5	1420	0.0591714	5.4362074258	32.88	25.636	56.782	23

saturation vapour pressure	**partial vapour pressure**	**Specific humidity**	**Enthalpy**	**Specific volume**	**Specific Enthalpy**
P_{SAT}	P_V	Ω	H	v	h
28	28.38	0.0179	78.969	0.852	45883.94584

In Table 5, an explanation of the rate of heat flow that occurs in heaters can be calculated and obtained q = 17546630.17 W/m^3 and Enthalpy on heater v = 1.289 m3/kg. Based on Table 6, an explanation of the characteristics of the drying room is influenced by the size of the area that affects the resulting drying capacity. The cross-sectional area on bed A = 1.912 m^2.

The type of bed used in the FBD component is the perforated plate. The needs of perforated plates in drying can be adjusted to the size of the material. The material needs can be adjusted to the size of the diameter, with the large provisions not exceeding the size of the material to be dried. The preparation tool carried out in this study is a thermometer that is used to determine the air temperature before arriving after the drying process. Thermometer 1 (T1) is placed in the airway after the blower to determine the air temperature in the environment and exhaled by the blower to the heater. Figure 2 shows a view of some of the FBD components.

Table 5. Characteristics of Heater Enthalpy on FBD

Length L (M)	**Power** P (Watt)	**Outer diameter** d_o (m)	**Radius** r_o (M)	**Heat flow rate** Q (W/m^3)	**Airflow discharge** Q (Watt/s)	**Ambient temperature of the air** Db °C	Wb °C	RH °C
0.3	500	0.011	0.0055	17546630.17	5.283044	32.88	25.63	56.782

Heater temperature Db	**Different temperature** ΔT	**Specific humidity** Ω	**Specific Enthalpy** H	**Specific volume** v	**Dew point temperature** Tdp	**Calculation** RH
°C	°C	Kg/kg		m^3/kg	°C	%
150	117.12	0.0179	0.248055	1.289266098	23	0.55585411

Table 6. Characteristics of Dryer Chamber on FBD

Heater temperature	**Material temperature**	**Air temperature on the material**	**Specific humidity on 150 °C**	**Specific Enthalpy**	**Bed**		**Airflow rate**	
					Diameter	area	Inside material	Outside material
Db	Db	Db	ω	h	Φ	A	q Air on the material	q Air after material
°C	°C	°C	Kg/kg		M	m^2		
150	50	48	0.0179	0.248055	1.56025	1.9109	47.403021	48.351081

Amount of water vapour moving	**The amount of water vapour that travels in 30 minutes**	**Specific humidity**	**Drying of specific humidity**	**Early air enthalpy**	**Drying air enthalpy**	**dryer airflow rate in 30 minutes**	**Air dryer specific volume**	**discharge of water vapor coming out of the material**
Ww	0.5	ω	Ω drying	H	H	q air dryer on the material	v	Q
Kg	Kg/hour	Kg/kg	Kg/kg	kJ/kg	kJ/kg	Kg/hour	m^3/kg	m^3/hour
0.003522615	0.00704523	0.0179	0.17701111	78.969	188	6.46168E-05	1.2333333	7.9694E-05

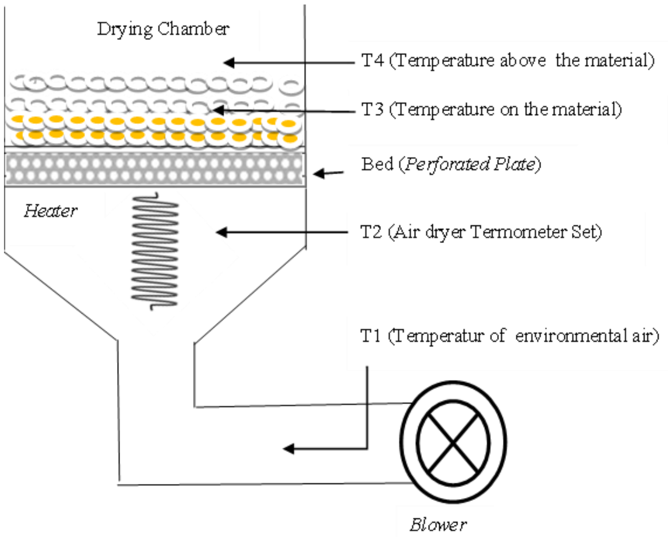

Figure 2. Main Components of FBD

Thermometer 2 (T2) is used to determine the air temperature of the dryer. Dryer air is air from blower gusts that pass through the heating room (heater) so that the air temperature increases (30). Thermometer 3 (T3) is the temperature of the material when the drying process takes place. Specific Humidity in an FBD is used to measure the amount of water in the air with the ratio to dry air vapor. The specific humidity measurement approach uses the help of sugar tech applications or uses Ph diagrams, as shown in Figure 3.

Additional equipment in this study is a digital scale used to determine the difference in weight of the material tested before and after drying. The material tested will be weighed first before the drying process, both in early dry conditions. Weighing after the drying process aims to find out the magnitude of the reduction in water content in the material. The following equipment is a timer that aims to find out the length of drying on the material to achieve optimal results. The presence of a blower as a dryer air supply into the dryer room is assisted by heat from the heater, making the heat in the dryer air reduced by several degrees from the control temperature. For example, the temperature of the heater control at 100 °C, it turns out that the dryer air receives heat not that much. That's what's interesting in this research.

The test was carried out with an initial mass of 316 grams of material, 150 °C heater temperature and temperature measurements in this experiment using 3 conditions, namely room temperature, temperature of the test material and temperature above the material. The calculation is done after the material is inserted bed dryer for 30 minutes in each experiment as shown in Table 7.

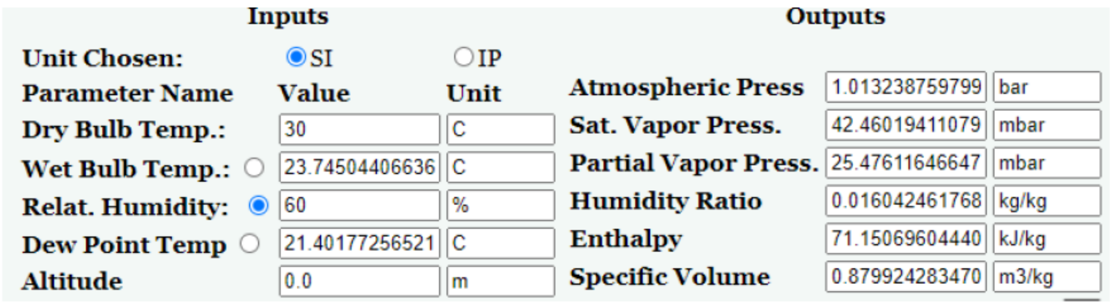

Figure 3. Specific Humidity

Table 7. Test Data at 50 °C

Temperature above the material	Temperature on the material	Room Temperature	Description
28.9 °C	28.6 °C	30 °C	When the machine is turned on
47.5 °C	50.5 °C	30 °C	Before the material is added
36.4 °C	43.8 °C	30 °C	When the material is added
48.6 °C	49.4 °C	30 °C	At minute 15
48.7 °C	49.5 °C	30 °C	At minute 20
49.0 °C	49.6 °C	30 °C	At minute 25
49.2 °C	50.0 °C	30 °C	At minute 30

Based on Table 7, it is calculated how much power, air flow, Enthalpy and flow rate occur in the drying process at that temperature. Based on the data, it is known that the blower is 85%, so data on the air flow rate of the blower can be obtained at 5.43621 W/s. At the same time, the Enthalpy that occurs in the blower is 40929.41 kJ/kg. Then the heat flow rate in the heater is q = 17546630,17 W/m3, and the Enthalpy on the heater with a heater power of 500 Watt is 1,354581119 m3/kg. It is a perforated plate bed with a bed cross-sectional area of 1.91134 m2 with a drying capability of q = 47.2396 W/m3.

The moisture content of dry products is 0.53 based on the calculation of the water content of raw materials based on lab results is 8.54%, so the amount of water that moves in the drying process can be calculated as 0.0346176 kg/hour. Therefore, the drying air flow rate in 30 minutes of the experiment can be known by calculation of 0.000295877 kg/hour and the air vapour discharge released from the material is 0.000364815 m3/hour.

Based on the calculations and lab results, Table 8 shows that the drying temperature of Qisthi Hindi at 50 °C can increase the calcium content in the ingredients. Therefore, the second test was carried out with an initial mass of 318 grams of material, 250 °C heater temperature and temperature measurements in this experiment using three conditions, namely room temperature, the temperature of the test material and temperature above the material as shown in Table 9.

Based on Table 9, it is calculated how much power, air flow, Enthalpy and flow rate occur in the drying process at that temperature.

a. Blower with η on the blower is 85 %, air flow data obtained on the blower is Q = 5.43621 Watt/s with the Enthalpy of air that occurs in the blower is h_u = 40929.41 kJ/kg

Table 8. Test Result Report: SIG.LHP.VI.2021.078733

Parameter	Unit	Result	Method
Calcium	mg/100g	489.04	18-13-1/MU/SMM-SIG (ICP-OES)
Protein	%	6.93	18-8-31/MU/SMM-SIG (Kjeltec)
Ash Rate	%	4.48	SNI 01-2891-1992, 6.1
Energy from fat	kcal/100g	9.09	Calculation
Total fat	%	1.01	18-8-5/MU/SMM-SIG point 3.2.2 (Weibull)
Water content	%	8.92	SNI 01-2891-1992, point 5.1
Total energy	kcal/100g	351.45	Calculation
Carbohydrate	%	78.66	18-8-9/MU/SMM-SIG

Table 9. Test Data at 100 °C

Temperature above the material	Temperature on the material	Room Temperature	Description
30.1 °C	28.5 °C	30 °C	When the machine is turned on
89.0 °C	90.7 °C	30 °C	Before the material is added
54.4 °C	61.2 °C	30 °C	When the material is added
66.6 °C	67.3 °C	30 °C	At minute 15
72.5 °C	76.2 °C	30 °C	At minute 20
86.1 °C	88.3 °C	30 °C	At minute 25
99.2 °C	100.0 °C	30 °C	At minute 30

b. Heater with 500-Watt power, the heat flow rate that occurs in the heater is *q* = 17546630.17 W/m3 with Enthalpy on the heater 1.354581119 m3/kg
c. Bed with a bed cross-sectional area of 1.91134 m2 with a drying power of *q* = 70.8549 W/m3
d. It is known that the water content of raw materials based on lab results is 8.54% = 0.0854
e. Initial mass = 0.636 kg/hour
f. Dry mass = 0.6 kg/hour
g. Material capacity = Initial mass - Final mass = 0.036
h. Dry product moisture content = 0.06

The calculations and lab results listed in Table 10 show that the drying temperature of Qishti Hindi at 100 °C decreases the ingredients' calcium content. The results are shown in Table 11, referring to the results of the calculations and the lab above.

At the drying temperature of the material at 50 °C, the calcium content increased because the moisture content was reduced by 5.3%. Meanwhile, at the drying temperature of the material at 100 °C, the moisture content has been reduced to 54 %. That is, when the drying process is continued at temperatures above 100 °C, there can be changes in the structure of the material (31). This should be avoided because it will damage the structure of calcium and calcium levels.

At a drying temperature of 50 °C, the calcium content increased by 29 % from the initial content of the raw material. During the initial laboratory testing, Qishi Hindi was tested in the form of roots and during testing with an FBD. The Qishi Hindi material was chopped into smaller sizes. This will facilitate the drying process so that the calcium content in the material will be easier to obtain when tested in the laboratory.

Meanwhile, at the drying temperature of the material at 100 °C, the calcium content decreased from drying at 50 °C 15 %. This happens because the water content in the material is significantly reduced. Reducing the water content in the material will cause structural damage to the material.

The best temperature for drying Qishti Hindi with FBD ranges from 50 °C - 100 °C. However, based on the analysis results above, it is not recommended to dry Qisthi Hindi with an FBD above 100 °C because it can change the material's structure.

Table 10. Test Result Report: SIG.LHP.VI.2021.079754

Parameter	**Unit**	**Result**	**Method**
Calcium	mg/100g	424.74	18-13-1/MU/SMM-SIG (ICP-OES)
Protein	%	6.46	18-8-31/MU/SMM-SIG (Kjeltec)
Ashes rate	%	4.50	SNI 01-2891-1992, 6.1
Energy from fat	kcal/100g	14.58	Calculation
Total fat	%	1.62	18-8-5/MU/SMM-SIG point 3.2.2 (Weibull)
Water content	%	4.06	SNI 01-2891-1992, point 5.1
Total energy	kcal/100g	373.86	Calculation
Carbohydrate	%	83.36	18-8-9/MU/SMM-SIG

Table 11. Comparison Result

Parameter	**Initial rate**	**Grade after drying 50 °C**	**Grade after drying 100 °C**
Calcium (mg/100g)	378.63	489.04	424.74
Protein (%)	6.72	6.93	6.46
Water content (%)	8.54*	8.92	4.06

* Root-shaped raw material

CONCLUSION

Drying using FBD was carried out at temperatures ranging from 50 °C - 100 °C. In air drying at 50 °C the protein content increased by 3.13 % and calcium content increased by 29 % from the level before drying, while the water content decreased by 5.3 %. At 100 °C drying air temperature the protein content decreased to 3.87 % of the protein content value before drying or 6.78 % protein content at 50 °C drying air temperature. This means that the protein content has been damaged at the drying air temperature above 50 °C. Meanwhile, at 100 °C drying air temperature, the calcium content decreased by 11.9 % from drying before drying or 13.4 % from calcium content at 50 °C drying air temperature. Meanwhile, the water content was reduced to 52.45 %. 1. This happens because the water content in the material is significantly reduced. Reducing the water content in the material will cause structural damage to the material. FBD was successful in reducing the moisture content significantly in the roots of the Qisthi Hindi plant which is a heat sensitive material.

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