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Original Research Article

The Influence of Inlet Air Temperature on Spray Drying Performance: A Study on Acha (*Digitaria exilis*) Sourdough Dehydration

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ABSTRACT

Spray drying is an effective way to dehydrate sourdough and extend its shelf life. The quality of the spray-dried product is a function of the process parameters. Therefore, this study aims to investigate the effect of different inlet air temperatures (120-180℃) on the performance of a spray dryer used for acha (Digitaria exilis) sourdough production. The findings showed that the outlet temperature increased with an increase in inlet air temperature while the relative humidity reduced. Thermal efficiency increased with an increase, in the inlet air temperature but leveled off for temperatures above 135℃. The maximum efficiency was about 76% at 135℃ inlet air temperature. The powder yield increases with an increase in inlet air temperature, reaching about 50% but reduces with further temperature increase. The minimum moisture content was about 3.7% at an inlet air temperature of 180℃. Inlet air temperature variation did not cause much difference in the evaporation rate. It varied from about 9.3 to about 9.4 g/min. The total titratable acids (TTA) increased with the increase in temperature of the inlet air. The maximum TTA was 1.7ml at inlet air temperature of 180℃. The pH did not vary much with an increase in inlet air temperature. It ranged from about 4.16 to 4.3. The microbial survival rate reduces with an increase in inlet air temperature. The maximum cell survival was recorded at 120℃. It was about 62% for LAB and 59% for yeast. The bulk density varied from 0.47 to 0.58 g/ml.

1. INTRODUCTION

The demand for rich gluten-free products is high due to increasing celiac disease worldwide (Olojede *et al.*, 2022). Application of biotechnology sourdough fermentation can improve the quality of gluten-free cereals, rendering the resulting product beneficial as a functional food (Nionelli *et al.*, 2016). Sourdough is a mixture of flour and water fermented by a microbial consortium of lactic acid bacteria (LAB) and yeast (Calvert *et al.*, 2021; Lau *et al.*, 2021; Reidzane *et al.*, 2021; De Vuyst *et al.*, 2023). Sourdough is often developed from wheat, but sourdough developed from acha (fonio whole grain) would have notable nutritional and health benefits compared to whole wheat flour. Apart from the fact that it is naturally gluten-free and antioxidant (Deriu *et al*., 2022), acha (fonio) is rich in carbohydrates, fat, fibre, vitamins, minerals, and sulfur-containing amino acids (Jideani, 2012; Ballogou et al., 2013; Enyiukwu *et al*., 2020). It has a higher protein content (Bako *et al*., 2020). Its methionine content is twice as much as egg protein (Chinwe *et al*., 2015).

Based on the production method, sourdough is classified into four types, type I, type II, type III and type IV (De Vuyst *et al*., 2017). Type I sourdough is a fresh sourdough that is reactivated by adding a part of the previous dough (Siepmann *et al*., 2018; Catzeddu, 2019; Lafuente et *al*., 2023). This type of sourdough occurs slowly, taking five to ten days to develop (Brandt, 2019). Type II sourdough uses selected strains of microorganisms for its fermentation (Tolu *et al* 2022; De Vuyst *et al*., 2023). This type of sourdough is for industrial use. In type III sourdough, the sourdough is produced and then subsequently dried (Reale *et al*., 2019). The combination of type I sourdough and type II sourdough gives sourdough, type IV (De Marco *et al*., 2022).

Due to unstable and high maintenance cost of type I sourdough, drying is employed for stabilisation. The drying extends the shelf life of the sourdough. In addition, the cost of production may be reduced (Caglar *et al*., 2021). In the literature, there are limited studies on the drying of sourdough, with freeze-drying being the preferred method due to greater cell preservation. However, this process is expensive and time-consuming (Huang *et al*., 2017). In contrast, spray drying is cheaper (Caglar *et al*., 2021). Furthermore, spray drying has a reasonable rate of cell survival and, is a continuous process but requires a comprehensive study of the drying conditions because they affect the powder yield, and powder quality (Peighambardoust *et al*., 2011; Rainer *et al*., 2018).

Spray drying consists of four stages (Master, 1991; Rainer, 2018): atomization, droplet-drying medium contact, droplet-to-particle conversion, and particle collection. The process starts by pumping the liquid sample into an atomizer, to convert it into a spray of fine droplets. These droplets are vaporized and transformed into dry particles by contact with the hot air in the drying chamber (Tafti *et al*., 2013). The dried particles are collected in a tank after being separated from the drying medium through a cyclone (Masters, 199; Santos *et al*., 2018). Flows in spray dryers can be concurrent, countercurrent, or mixed. Co-current flow arrangement is the most popular (Rainer *et al*., 2018). This study aims to investigate the effect of inlet air temperature on the performance of spray dryer, used for production of stable acha or fonio (*digitaria exilis*) sourdough. To the author's knowledge no work has been published in the open literature on the spray drying of acha sourdough.

2. MATERIALS AND METHODS

2.1. Sourcing of Materials and Preparation

Dehulled acha (*Digitaria exilis*) grains obtained from Kenyi, Kagarko Local Government Area of Kaduna State, were manually sorted to remove extraneous materials like stones, stalks, and chaffs. The sorted grains were washed with potable water to remove adhering dust and to bring down the initial microbial load. The remaining stones still present in grains were separated by sedimentation technique and oven-dried at 50℃. A closed circuit grinding was used to mill about 5 kg of the dried grains into flour using a sterile laboratory-size ball mill. The milled product was sieved through a 63 μm sieve.

2.2. Sourdough Production

Acha sourdough was developed following the approach of Edema *et al*. (2013) but with modification. Thus, the acha flour was mixed with tap water in a ratio, of 1:1.5 in a sterile 3L transparent container and stirred thoroughly until no dry spot was noticed. The container was covered with clean tea cloth, and the mixture was allowed to spontaneously ferment at room temperature (25-29 °C). The process was propagated by back-slopping (feeding) every 24 h for 6 days. This involved adding 50 % of the previous sourdough to a new fresh mixture of acha flour and water for these 6 days. At the end of the 6 days, a mature sourdoughs characterized by the development of bubbles, the disappearance of the rotten milk odour, and pH was formed (Roby *et al.* 2020).

2.3. Spray drying of Acha Sourdough into Powder

The fresh sourdough was diluted to 10% solid and then spray dried using a pilot plant spray dryer (Armfield FT 80), equipped with a variable-speed progressing cavity and a pneumatic nozzle. The drying gas enters from the top of the cylindrical dry chamber in co-current flow with the solution drops at the set inlet temperature. Figure 1 is a representation of the spray dryer set-up. The spray drying experiments were carried out at inlet air temperatures of 120, 130, 135, 140, 145, 150, 160, 170, 175, and 180℃. In each experiment, the feed batch size, feed flow rate, drying air flow rate, and atomizing air pressure were kept constant at 500 ml, 4Hz, 35Hz, and 3bar respectively. Dried powder was collected at the base of the dryer chamber and the base of the cyclone separator, and weighed. The sourdough powder samples were stored in air-tight-capped plastic containers and kept in the dark at room temperature for analysis.

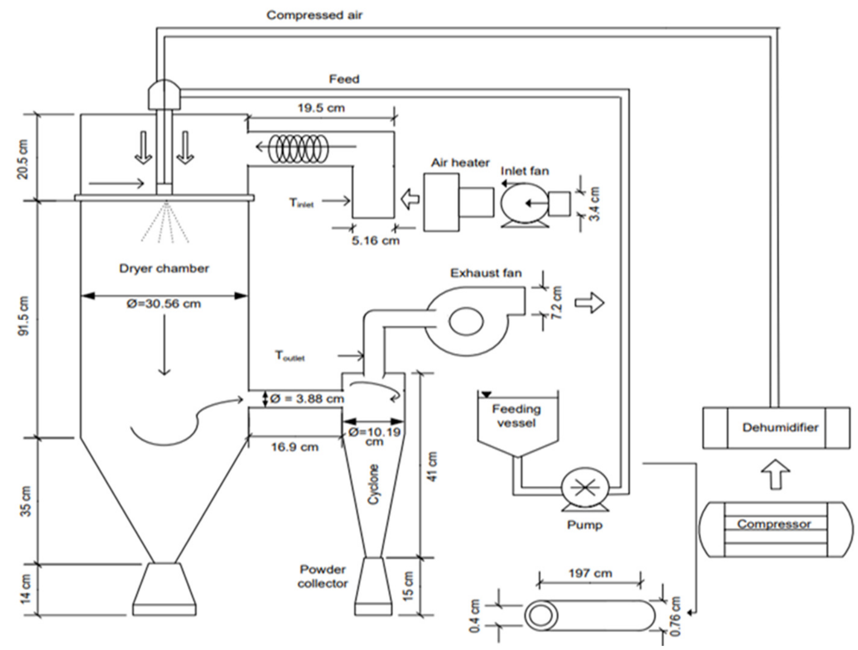

Figure 1: Schematic representation of the pilot scale FT80 tall form spray dryer

2.4. Measurement of Spray Dryer Performance

2.4.1. Exit air temperature

Process parameters such as the inlet and outlet temperature of the drying medium, influence considerably the physicochemical properties of the produced powders (Jain *et al*., 2012). At each inlet air temperature, the exit air temperature that was indicated on the control panel of the spray dryer was recorded.

2.4.2. Exit air humidity

The outlet air relative humidity for each inlet air temperature was taken from the reading on the control panel.

2.4.3. Powder yield

The powder yield (PY) in each batch of the experiment was calculated using Equation (1) (Tontul and Topuz 2017):

$$PY = \frac{\text{Weight of powder dry collected from the collection points}}{weight\ of\ total\ solids\ in\ the\ feed} \times 100 \tag{1}$$

2.4.4. Efficiency of spray dryer

The efficiency of the spray dryer was described in terms of the overall thermal efficiency of the spray dryer (TE) and approximated by Equation (2) (Goula *et al*., 2003; Cheng *et al*., 2023):

$$TE = \frac{T_{inlet} - T_{outlet}}{T_{inlet} - T_{atm}} \quad (2)$$

2.4.5. Evaporation rate

Evaporation rate (ER) was calculated using Equation (3) (Bahnasawy *et al.*, 2010):

$$\text{ER(g/min)} = \frac{Feeding\ rate\ (g/min) \times (\%Total\ solid\ in\ powder - \%Total\ solid\ in\ feed)}{\%Total\ solid\ in\ feed} \quad (3)$$

2.4.7. Moisture content

The Official Methods of Analysis of the Association of Analytical Chemists (AOA, 2000) was used to determine the moisture content of the powders. About 5g of sample was weighed and dried at 103 ℃ to constant weight, using an oven.

2.4.8. pH and total titratable acid (TTA) determination

To determine the pH, about 1 g of the sourdough mixed with 9 ml of distilled water. A pH meter (Fisher Scientific accumet AE150) which had been standardized with buffer solution, was used to measure the pH of the mixture. Measurement of titratable acid (TTA) produced in the sourdoughs was done according to AOAC (2000). Sourdough and distilled water were mixed in a ratio of 1:9 and 3 drops of Phenolphthalein indicator were added. The mixture was titrated against 0.1 M NaOH. The TTA was expressed as the amount (ml) of 0.1 N NaOH necessary to achieve pH of 8.3.

2.4.9. Microbial enumeration

To determine the number of microorganisms (per g) in the liquid sourdough or spray-dried sourdough, about 1 g of the sourdough was suspended in a 9 ml saline solution (0.85% (w/v) Sodium chloride). The serial dilution of the mixture was done. From appropriate, tenfold dilutions the microbial enumeration was made by pour plate technique, using plates with 30–300 colonies. Lactic acid bacteria (LAB) was enumerated on MRS agar (Merck, Darmstadt, Germany), after incubating anaerobically for 48 h at 35 °C. Yeasts enumeration was determined on potato dextrose agar (PDA) (HiMedia, Mumbai, India), after incubating for 72 h at 27 °C.

2.4.10. Determination of LAB and yeast survival rate after sourdough spray drying

The rate of survival of LAB or yeast due to the spray drying was evaluated by the formula:

$$\text{Survival rate} = (\text{Log N}/\text{Log No})\ \text{X}\ 100 \quad (4)$$

Where: N_0 represents the number of CFU/g of LAB or yeast in unsprayed dried (liquid acha sourdough) lactic in the cell concentrate, and N indicates the number of viable cells (CFU/g) in spray-dried sourdough after drying.

2.4.11 Bulk density measurement

An empty graduated cylinder of Volume (25 ml) was weighed, (W1). Gently filling the cylinder with the powder sample up to the 25ml mark, the bottom of the cylinder was tapped several times on the laboratory bench until there was no further reduction and it was weighed (W2). The bulk density was calculated as:

$$\text{Bulk density} = (\text{W2} - \text{W1})\ \text{g}/25\text{ml} \quad (5)$$

3. RESULT AND DISCUSSION

3.1. Effect of the Inlet Air Temperature on Outlet Air Temperature and Relative Humidity

The outlet temperature is the temperature of the drying gas and the dry particles before entering the collection system (Grigoriev *et al.*, 2022). The effect of the inlet air temperature on the exit air temperature and relative humidity (RH %) is shown in Figure 1.

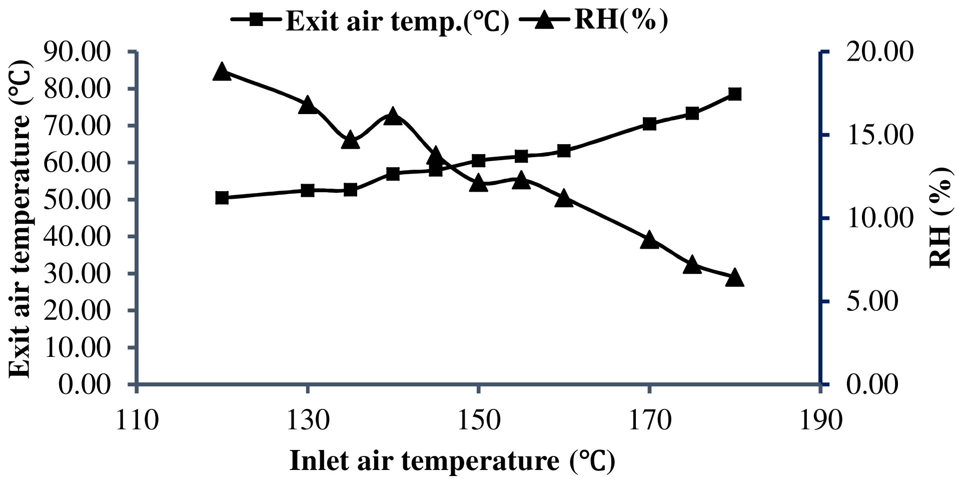

Figure 1: Effect of inlet air temperature on exit air temperature and relative humidity

The outlet air temperature increases with an increase in the inlet air temperature. An increase in the outlet air temperature leads to an increase also in humidity, but a reduction in relative humidity (Bhandari, 2008; Santos *et al.*, 2018). At higher inlet air temperature, more water vapour was accommodated before reaching saturation, thus lowering the relative humidity of air exiting the dryer (Schuck *et al.*, 2008). The outlet air temperature varied from about 50 to 79°C, while the relative humidity changed from 19 to 7%. The exit air relative humidity varies inversely with the inlet air temperature. Schuck *et al.* (2008), Cheng *et al.* (2018), Reale *et al.* (2019) and Anis *et al.* (2022) reported similar trend of result.

3.2. Effect of the Inlet Air Temperature on Overall Thermal Efficiency and Evaporation Rate of the Spray Dryer

The overall thermal efficiency of the spray dryer gives an estimate of the fraction of total energy supplied to the dryer used in the evaporation process (Goula *et al.*, 2003). A correction factor (1-R/100), proposed by Hall and Hedrick (1971) is sometimes introduced to take care of the radiation losses of the dryer. The letter R is the loss factor. For this study, R was assumed to be zero. The effect of the inlet air temperature on the thermal efficiency and evaporation rate of the spray dryer is shown in Figure 2.

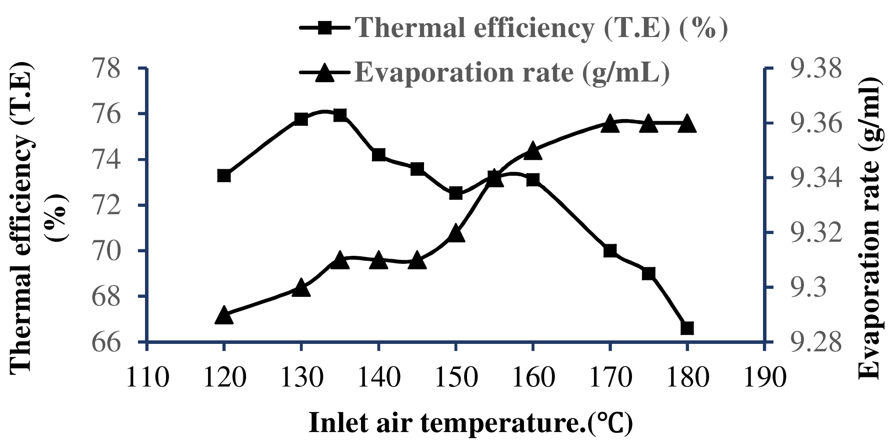

Figure 2: Effect of inlet air temperature on thermal efficiency and evaporation rate

The overall thermal efficiency increased with an increase in inlet air temperature, but above 130°C, it began to reduce. The decrease in thermal efficiency with an increase in the inlet drying air temperature, may suggest a faulty measurement of the temperatures. Sim et al. (2023) also reported decrease in thermal efficiency due to increase in inlet air temperature. An investigation conducted by Cheng *et al.* (2021) showed that the thermal efficiency of spray dryers increases with an increase in inlet and air temperature, but reduces with an increase in outlet air temperature. This showed that the thermal efficiency could be increase by increasing the inlet air temperature and reducing the outlet air temperature. Fixing the inlet air temperature is a function of the product to be spray-dried.

The evaporation rate varied from 9.29 to 9.36 g/min. The evaporation rate of the liquid feed increases with an increase in inlet air temperature. Higher inlet air temperatures provide more energy for the liquid droplet to evaporate faster, hence quicker drying of the liquid feed. This phenomenon parallels the results of some previous studies (Bahnasawy 2010; Saha *et al.*, 2018; Himmetagaoglu *et al.*, 2019; McDonagh *et al.*, 2020). However, it is essential to consider the specific requirement of the material to be processed. In spray drying of material with microbes such as sourdough, the inlet air temperature must be control to improve the viability of the microbes in the resulting powder (Dongbiao *et al.,* 2023). In Figure 2, from 170 to 180℃ the evaporation rate remained almost constant, at 9.36 g/minute. This could be that the higher air temperatures led to increase water concentration in the air, which reduced the driving force for evaporation ($\Delta P = saturated\ pressure - vapour\ pressure$).

3.3. Influence of Inlet Air Temperature on Powder Yield (%) and Moisture Content

Powder yield and moisture content are key parameters when considering the feasibility of the spray-drying process. The effect of inlet air temperature on powder yield and moisture content of sourdough is shown in Figure 3.

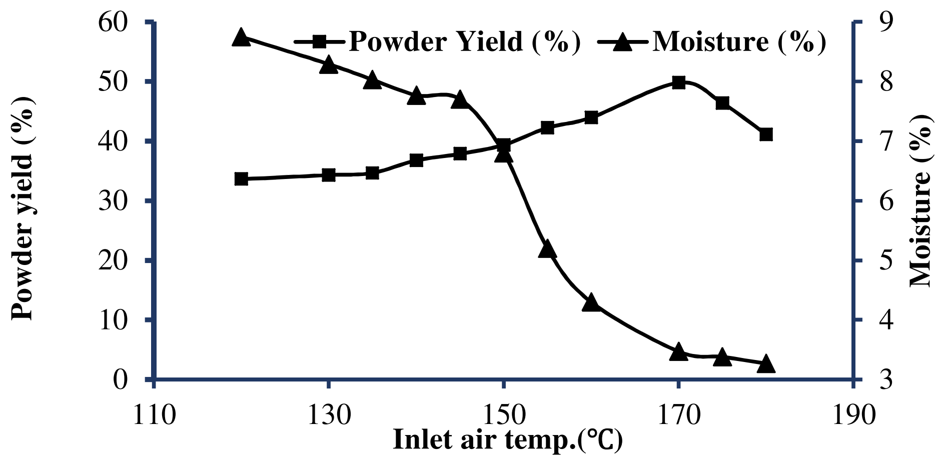

Figure 3: Influence of inlet air temperature on powder yield (%) and moisture content

From 3, it can be seen that the powder yield (%) increased with an increase in inlet air up to 170℃ and leveled off for higher temperatures. The increase in the powder yield due to increase in the inlet air temperature can be link to the lowered moisture content of powder particles at a higher inlet temperature, which reduces wall deposition. Furthermore, lower relative humidity at higher air temperatures, also greatly reduces the liquid bridging phenomena between the powder and the surfaces (Sim *et al.*, 2023). Telang and Thorat (2010), and Tay *et al.* (2021) reported similar results. The fall in the powder yield (%) at higher inlet air temperature could be attributed to the formation of wall deposits in the drying chamber. Wall deposits in spray dryers occur when food materials are spray-dried at temperatures beyond, their glass transition temperature. The highest yield obtained was about 50 % at 170℃. The shelf life of the dried product is closely related to its moisture content (Atalar and Dervisoglu 2014).

Moisture content and water activity are also important for good spray-dried powder characteristics, such as high flow ability, low stickiness, agglomeration, and maximum microbial viability (Behboudi Jobbehdar *et al.*, 2013). From Figure 3 as the inlet air temperature increases, the moisture content of the powder product reduces. The moisture content of the powder drastically reduced from 9 to 3 as the inlet air temperature changed from 120 to 180℃. At high inlet temperatures, more heat gradient exists between drying air and the atomized feed (Golman and Julklang, 2014). The higher inlet temperatures promote heat transfer into the particle, which in turn enhances the rate of moisture evaporation from the sprayed material, resulting in lower moisture content (Zare *et al.*, 2012; Jain, 2017; Azhar *et al.*, 2021; Tay *et al.*, 2021). water moisture content below 5% is recommended for food powders containing probiotics because the amount of water remaining after drying affects the rate of loss of cell viability during subsequent storage (Reale *et al.*, 2019). In this study, the lowest moisture content obtained was about 4 % and the inlet air temperature was 170℃. This was also the temperature with the highest powder yield.

3.4. Influence of Spray Dryer Inlet Air Temperature on LAB and Yeast Viability

The influence of spray dryer inlet air temperature on LAB and yeast viability is shown in Figure 4. From the figure, it can be seen that the inlet air temperature influences, the viability of microbes. The viability LAB and yeast reduces with an increase in temperature. In spray-drying probiotics, the spray dryer outlet air temperature influences the viability of cells. Reale *et al.* (2018) reported that the outlet air temperature that is proportional to the inlet air temperature of the spray dryer, affects the survival of lactic acid bacteria and yeasts. Similarly, Peighambardoust, *et al.* (2011) stated that the outlet air temperature is the major drying parameter affecting the viability of spray-dried starter cultures. From Figure 1, the spray dryer outlet air temperature varies almost proportionately with the inlet air temperature. Therefore, it is not surprise to note that survival rates of LAB and yeast reduced with increase in the inlet air temperature.

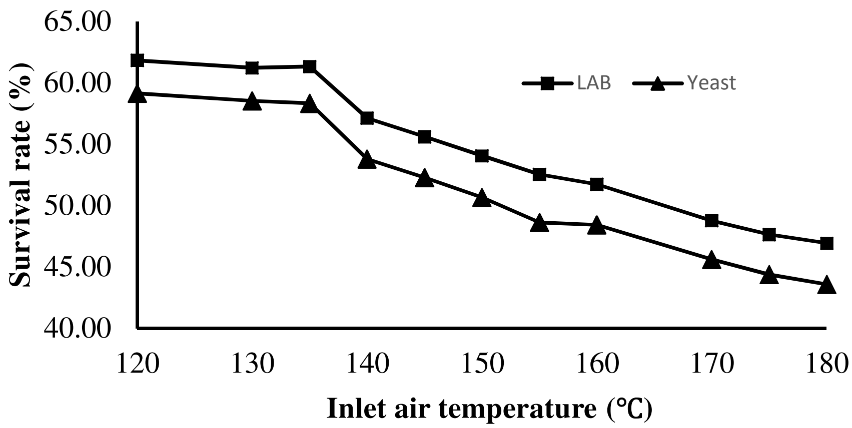

Figure 4: Influence of spray dryer inlet air temperature on LAB and yeast viability rate

From Figure 4, the survival rate of LAB varied from about 61 % to 47 % due to increase in inlet air temperature from 120 to 180℃. The yeast survival rate of yeast was about 59% at 120 ℃ and about 44% at 180℃. During spray drying of the sourdough, the microbes were subjected to mechanical, thermal, osmotic, and oxidative stresses. The stresses hurt the microbial survival rate (Liu *et al.*, 2018; Schutyser *et al.*, *2019*). Behboudi-Jobbehdars *et al.* (2013) reported that the loss of probiotics viability during convective thermal processing is connected to cellular injuries due to the combined effect of heat and mechanical stress. Figure 4 shows the severity of stress due to inlet air temperature.

3.5. Influence of Inlet Air Temperature on TTA (Total Titratable Acid) and pH

The TTA measures the quantity of total organic acid (lactic acid, acetic acid, propionic acid, butyric acid), while the pH indicates the extent of hydrogen ions in the sourdough. Figure 5 shows the effect of inlet air temperature on the TTA and pH of the spray dried. The TTA and pH of the sourdough vary from 1.02 to 1.73 ml and 4.16 to 4.20 respectively. In Figure 5, it can be seen that the inlet air temperature has a positive effect on TTA, but on the pH, the effect is not very much. The highest TTA was 1.73ml at an inlet air temperature of 120℃. Caglar *et al.*, 2021 studied sourdough spray drying, and stated that the TTA of the spray-dried sourdough was much higher than that of fresh sourdough. They found that the pH of the spray-dried sourdough, did not differ much from the fresh sourdough.

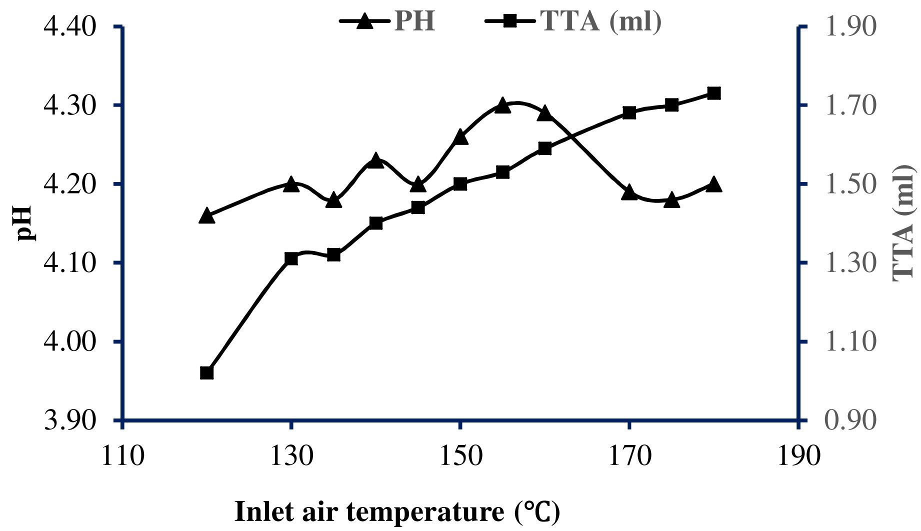

Figure 5: Influence of inlet air temperature on TTA (total titratable acid) and pH

3.6. Effect of Inlet Air Temperature on Bulk Density

Bulk density is an important powder parameter. It influences the physical characteristics of powder including dispersibility and wettability. Bulk density can be attributed to the shape and surface morphology of the particle (Caglar *et al.*, 2021). Tafti *et al.* (2013) reported that inlet air temperature influences the bulk density of powders. The effect of the inlet air temperature on the sourdough bulk density is shown in Figure 6. The figure shows that the bulk density of the spray-dried sourdough decreases with an increase in temperature. Jain *et al.* (2021) reported a similar finding when they studied beetroot juice spray drying. In contrast, Ishiwu *et al.* (2014) reported an increase in powder density due to increase in drying temperature. In this study, the highest bulk density was about 0.58 g/ml at 120℃, while the lowest was about 0.47, at 180℃.

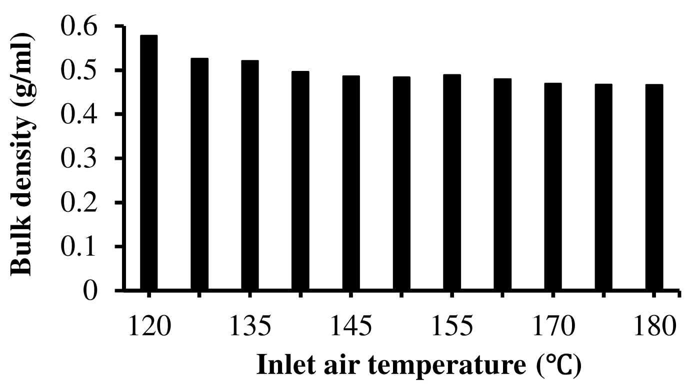

Figure 6: Impact of inlet air temperature on bulk density

4. CONCLUSION

The advantages of sourdough powder over fresh sourdough include longer shelf-life, constant product quality, ease of formulation, and lower transportation costs. Spray drying of acha (*Digitaria exilis*) sourdough was investigated. The result shows that fresh acha sourdough can be stabilized through spray drying. The powder yield (%) increased with an increase of inlet air temperature up to 170 ℃ but levels off above this temperature probably due to wall deposits. Lower moisture content was obtained at higher inlet air temperatures. The lowest moisture content showed that the spray-dried sourdough can be stored for future use. The thermal efficiency was found to reduce with an increase in temperature. This showed that manipulation of other spray drying parameters is needed. The TTA of the sourdough powder was found, to increase with increase in the inlet air temperature. The pH was found to be within acceptable range. Variations in the inlet air temperature did not affect the pH of the sourdough powder. Microbial survival rate was negatively affected by the inlet air temperature. In summary, the result of this study showed that spray drying can be used to dehydrate acha sourdough, but a tradeoff between powder yield and microbial survival is required. Optimization of the entire spray drying parameters can provide this trade-off.

5. ACKNOWLEDGMENT

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6. CONFLICT OF INTEREST

There is no conflict of interest associated with this work.

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