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INVESTIGATING THE IMPACT OF FEED RATE ON THE SPRAY DRYING PROCESS OF ACHA (*DIGITARIA EXILIS*) SOURDOUGH

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ABSTRACT
Acha (Digitaria exilis) is a cereal crop, rich in carbohydrates, dietary fibre, minerals, and amino acids. Acha sourdough in powder form has several advantages including longer shelf life, constant product quality, and low cost of maintenance and transportation. This study aims to investigate the impact of feed rate on the spray drying process of acha (Digitaria exilis) sourdough into powder form. A fresh acha sourdough was prepared and spray-dried into powder at different feed pump rates (3, 3.5. 4, 4.5, and 5 Hz). Performance indicators of the process were analyzed. The spray dryer exit air temperature ranged from 70 ℃ to 55℃, while the relative humidity varied from 7% to 21%. The thermal efficiency and evaporation rate ranged from about 67% to 79% and 4.5 g/min to 13.0 g/min respectively. Powder yield and moisture, respectively varied from 45% to 50% and 8 % to 5%. The maximum powder yield of 50% was achieved at a feed pump rate of 4Hz. The viability of Lactic acid bacteria and yeast ranged from about 4.9 log (CFU/g) to 6 log (CFU/g) and 4.6 log (CFU/g) to 5.8 log (CFU/g) respectively. The total titrable acid ranges from 1.5 ml to 1.6 ml, while the pH varied from 4.3 to 4.2. The bulk density varied from about 4.6 g/ml to 6.0 g/ml. The results showed that the spray-drying approach produced stable sourdough powder with standard functional properties for production of gluten-free baked foods.
Keywords: *Acha; feed rate; ; impact; sourdough; and spray-drying***1.**

INTRODUCTION

Sourdough is a mixture of flour and water, fermented by a microbial consortium of lactic acid bacteria (LAB) and yeast (Calvert *et al*., 2021; De Vuyst *et al*., 2017; De Vuyst *et al*., 2021; De Vuyst *et al*., 2023). Research on the application of biotechnology to develop sourdough-based food has increased due to its health benefits (Olojede *et al*., 2023). Besides, due to whole grain fermentation with LAB and yeasts, sourdough is rich in bioactive compounds such as phenolic acids and bioactive peptides (Luti *et al*., 2020). The total titratable acids (TTA), and pH of the sourdough are an indicator of the quality of the sourdough fermentation. The TTA is the total acidity of the sourdough, including both organic and inorganic acids, while the pH reflects the concentration of hydrogen ions. The pH and TTA can also indirectly indicate the level of microbial activity in the sourdough. A lower pH and higher TTA indicate higher acidity. Most sourdoughs are wheat-based. Recently attention has shifted towards gluten-free cereals such as acha (*Digitaria exilis*) whole grain, due to its enhanced nutritional and health benefits compared with wheat flour (Babatuyi *et al*., 2023).

The application of sourdough in baked foods is challenging due to the difficulties and costs of maintaining a live microbial culture. To mitigate this issue, sourdough is dried to stabilize the microbes (Albagli, *et al*., 2019; Caglar *et al*, 202, Montemurro *et al*., 2019; Reale *et al*., 2021). Different drying approaches such as freeze-drying, spray drying, drum drying, oven drying, and fluidized bed drying have been used to dehydrate sourdough (Brandt, 2019). Reale *et al.* (2019) suggested that a stabled sourdough requires moisture content to be less than 7%, because high moisture content can trigger unwanted biochemical and microbiological processes in the dried powder. Tan *et al*. (2018) stated that dried sourdough is easy to store, transport, and market, but drying at high temperatures may reduce the survival of yeast and LAB cells due to heat stress during dehydration. Huang *et al*. (2017) relate the cell viability during drying, to the applied method, process parameters, and the use or absence of protectant compounds. In literature, freeze-drying offers greater cell viability but is expensive and time-consuming. In contrast, spray drying is a cheaper method, a continuous process, and is good for a large-scale production (Caglar *et al*., 2021). Besides, spray-drying has a reasonable rate of cell survival but requires a comprehensive study of drying conditions, equipment configurations, vis-a-vis feed material, powder yield, and powder quality (Peighambardoust *et al*., 2011). The spray drying process comprises three phases: atomization, droplet-to-particle conversion, and particle collection (Moreira *et al*., 2021). In the atomization stage, the atomizer converts the feed into fine droplets. These droplets dried, on contact with the hot air in the drying chamber. The dried particles separate from the drying medium through a cyclone, and are collected in a container (Santos *et al*., 2018). A high cell survival rate in spray drying is accomplished based on the optimization of drying parameters and the use of cell-protective agents (Mantzourani *et al*., 2019; Mohd Roby *et al*., 2020; Peighambardoust *et al*., 2011; Stefanello *et al*., 2019). Studies on the spray drying of sourdough have been reported in the literature (Caglar *et al*., 2021; Ilha *et al*., 2015; Reale et al., 2019; Rozylo *et al*., 2015; Tafton et al., 2013a; Tafti *et al*., 2013b). To the best of author's knowledge, no work related to spray drying of acha sourdough is found in the open literature. This study aims to investigate the impact of feed rate on the spray drying process of acha (*Digitaria exilis*) sourdough.

2. MATERIAL AND METHODS

2.1 Production of Sourdough and its Spray Drying

Dehulled acha (Digitaria exilis) was sourced from Kenyi, Kagarko local Government Area of Kaduna state. The acha was thoroughly washed with potable water, to remove adhering dust on the grains and reduce microbial load. Sedimentation technique was used to separate sand particles from the acha grains, and then the grains were oven-dried. The dried grains were milled into flour using a sterile laboratory-sized ball mill. The milled product was sieved through a 63-mµ sieve.

Acha sourdough was prepared following the approach of Edema *et al*. (2013) but with modification. 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 a clean cloth, and the mixture was allowed to spontaneously ferment at room temperature. The process was propagated by back-slopping (feeding) every 24 h, adding 50 % of the previous sourdough to a fresh mixture of acha flour and water for 6 days. Lactic acid bacteria count, yeast count, pH, and total titratable acid (TTA) of the sourdough were determined.

The fresh sourdough was diluted to 10% solid, and drying was made using a pilot plant concurrent flow spray dryer (Armfield FT 80). The sourdough was pumped into the drying chamber using a progressive cavity pump and atomization was performed using a two-fluid nozzle (nozzle inside diameter 1 mm). To study the effect of feed pump rate, experiments were performed at different feed pump rates (3, 3.5, 4, 4.5, and 5Hz). In all experiments, inlet air temperature, inlet air fan rate, exit air fan rate, atomizing air pressure, and sample size were kept constant at 170°C, 35 Hz, 40Hz, 3bar and 500 ml respectively. The sourdough powder samples obtained were collected in an air-tight-capped plastic containers and kept in the dark at room temperature, for further analysis.

2.2 Evaluation of the spray drying process

2.2.1 Exit air temperature

Process parameters including outlet temperature influence considerably the physicochemical properties of the produced powders (Jain *et al*., 2012). At each inlet air temperature, the exit air temperature was taken from the display on the control panel.

2.2.2 Exit air humidity

The outlet air relative humidity at each inlet air temperature was gotten from the reading display on the control panel.

2.2.3 Powder yield

Powder yield (PY) was determined according to Equation (1) (Tontul *et al*., 2017):

$$PY = \frac{weight\ of\ powder\ obtained}{Weight\ of\ total\ solid\ in\ feed} \times 100 \qquad (1)$$

2.2.4 Efficiency of spray dryer

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

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

Where: TE = Thermal efficiency (%)

T_{inlet} = Inlet air temperature (°C),

T_{outlet} = Outlet air temperature (°C),

T_{atm} = the atmospheric temperature (°C).

2.2.5 Evaporation rate

The evaporation rate (ER) was determined according to Equation (3) (Bahnasawy *et al*., 2010):

$$ER = \frac{FR \times (\%TS_{Powder} - \%TS_{feed})}{\%TS_{feed}} \qquad (3)$$

Where: ER = Evaporation rate (g/min),

FR = Feed rate (g/min),

TS_{powder} = Total solids in powder,

TS_{feed} = Total solids in the feed.

2.2.6 Moisture content (MC)

The moisture content of the powder was determined following the official methods of analysis of the Association of Analytical Chemists (AOAC, 2000). About 5g of the sample in an aluminum plate was placed in a drying oven, dried at 103℃ until constant weight. Percentage moisture content was calculated using Equation (4):

$$MC = \frac{W_2 - W_3}{W_2 - W_1} \times 100 \qquad (4)$$

Where: $MC = Moisture\ content\ (\%)$,
$W_1 = Weight\ of\ empty\ dish$,
W_2 = Weight of dish with sample before drying,
W_3 = Weight of dish with sample after drying.

2.2.7 Total titratable acid (TTA) and pH

About 1 g of the sourdough was mixed with 9 ml of distilled water. The pH of the mixture was carried out using a pH that had been standardized using buffer solutions. Readings (in triplicates) were taken on the pH meter scale.

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 solution, and the TTA was expressed TTA as the amount (ml) of 0.1 M NaOH necessary to achieve pH of 8.3.

2.2.8 Microbial enumeration

About 1 g of the sourdough was suspended in a 9 ml saline solution (0.85% (w/v) sodium chloride). The mixture was serially diluted. From appropriate tenfold dilutions, the microbial enumeration was made by pour plate technique using plates with 30–300 colonies. The LAB was enumerated on MRS agar (Merck, Darmstadt, Germany) and incubated anaerobically for 48 h at 35 °C while the yeast enumeration was determined on potato dextrose agar (PDA) (HiMedia, Mumbai, India) and incubated for 72 h at 27 °C.

2.2.9 Bulk density

An empty graduated cylinder of volume (25 ml) was weighed, (W_1). The cylinder was filled with the powder sample up to the 25ml mark gently, tapped several times on a laboratory bench, and more powder sample was added until there is no space for more. The filled cylinder was weighed, (W_2). Finally, the bulk density was calculated as:

$$Bulk\ density = \frac{(W_2 - W_1)g}{25ml} \qquad (5)$$

3 RESULTS AND DISCUSSIONS

3.1 Effect of feed Pump Rate on Exit Air Temperature (EAT) and Relative Humidity (RH)

The influence of the feed pump rate (FPR) on exit air temperature (EAT) and relative humidity (RH) is shown in Figure 1. The EAT and the RH varied from about 71℃ to 55℃ and 7% to 21% respectively. The EAT

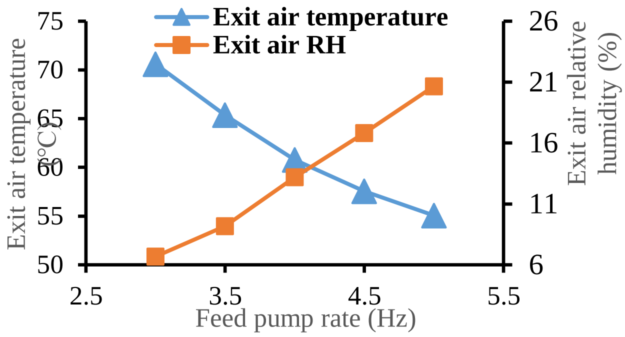

Figure 1. Effect of Feed Pump Rate on exit air temperature and relative humidity

reduces, with an increase in the FPR, while the RH increases, with an increase in the FPR. These trends occurred because an increase in FPR increases the cooling effect of evaporation. An increase in FPR also leads to more liquid flow and bigger droplets into the air stream (Pinon-Balderrama *et al.*, 2020). These droplets absorb more heat from the air, widening the difference between the temperatures of the inlet air and the exit air. Furthermore, the air gains more water vapour, leading to an increase in its relative humidity. Tan *et al.* (2011) earlier reported a similar trend of results.

3.2 Effect of Feed Pump Rate on Thermal Efficiency (TE) and Evaporation Rate (ER)

The variation of thermal energy (TE) and evaporation rate (ER) due to feed pump rate (FPR) is shown in Figure 2. The TE and DR increase, with an increase in the FPR. The TE and ER ranged from 67 to 79 % and 4.5 to 13.0 g/min respectively.

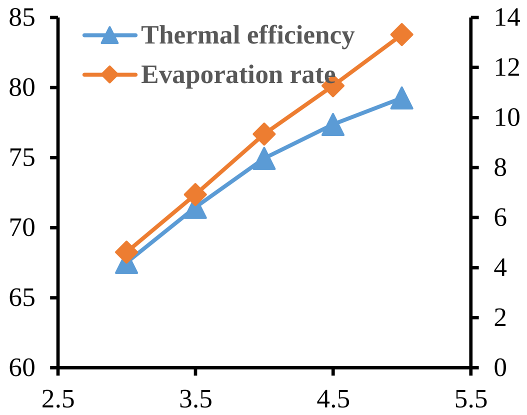

Figure 2. Effect of Feed Pump Rate on Thermal Efficiency and Evaporating Rate

The TE of the spray dryer increases with an increase in the FPR because an increase in FPR, increases liquid available to the hot air for evaporation. With more liquid available to the hot air, heat utilization is increased, and reflected as an increase in TE. An increase heat utilization also mean an increase moisture removal from the material, which appears as an increase in ER. Golman and Julklang (2014) evaluated the performance of a spray dryer and reported that the thermal energy efficiency of the spray dryer increased, with an increase in the feed flow rate.

3.3Effect of Feed Pump Rate on Powder Yield (PY) and Moisture Content (MC)

The quantity of powder obtained in the spray drying process via cyclone separation is influenced by the drying air flow and local velocities, the spatial geometry of the cyclone separator, and the interaction of the particles with the cyclone walls (Behboudi-Jobbehdar *et al*., 2013). In this study, the airflow was kept constant. Therefore, parameters that affect the surface stickiness of the microparticles such as the hygroscopicity, glass transition temperature, moisture, and temperature of the droplets in the drying chamber detect the powder recovery. The influence of FPR on PY and MC is shown in Figure 3.

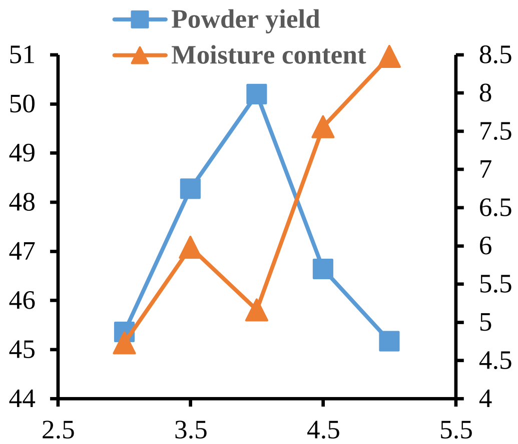

Figure 3. Effect of Feed Pump Rate on Powder Yield and Moisture Content

The PY increased, with an increase in FPR but later decreased with an increase in the FPR. The maximum PY attained was about 50 % at an FPR of 4Hz. The moisture content (MC) continues to increase, with an increase in the FPR. The MC varied from 4.7 to 8.5%. Authors including Chegini and Ghobadian (2005), Jain *et al.* (2017), and Hong *et al*. (2021), reported similar pattern of results. The possible explanation to these scenarios is that an increase in FPR shortens the contact time of the feed droplets with the hot air, hence lessening evaporation. A reduction in evaporation increases the MC and density of the powder. An increase in density can increase the powder yield due to an increment in weight per unit volume. However, beyond FPR of 4Hz, the MC of the powder might have increased to the level of causing powder particles to stick to dryer walls, reducing the PY.

3.4 Effect of Feed Pump Rate on Lactic Acid Bacteria (LAB) and Yeast Viability

When a Sourdough is spray-dried, the viability of LAB and yeast cells is reduced (Caglar *et al*., 2021). During spray drying, the LAB and yeast cells suffer mechanical, thermal, osmotic, and oxidative stresses which reduced their viability (Khemetal *et al*., 2015; Liu et al., 2018; Schutyser *et al*., 2019).

Figure 4 shows the effect of FPR on the viability of LAB and yeast. The viability of LAB and yeast varied from about 4.1 to 5.00 and 3.9 to 4.5 log (CFU/g) respectively.

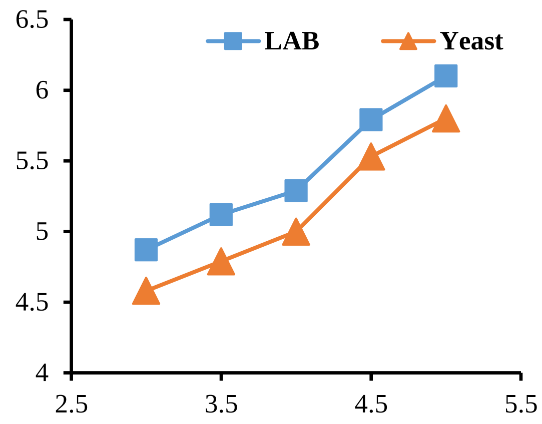

Figure 4. Effect of Feed Pump Rate on Viability of Lactic Acid Bacteria and Yeast

The viability of LAB and yeast increases with an increase in FPR. This is because an increase in the FPR increases the feed flow rate. An increase in the feed flow rate reduces the residence time of the particles in the dryer chamber, likewise the EAT. A reduction in particle residence time, and EAT lowers thermal stress on the microbes, favouring their survival. This agrees with the findings of Atalar and Dervisoglu (2015) who investigated the effect of spray drying parameters on kefir powder. These authors reported that a high feed pump rate and low exit air temperature favoured the survival rate of lactococci. The microbial count of the spray-dried sourdoughs obtained in this study, satisfied the minimum requirement set by FAO/WHO of 6.27 log CFU/g of live organisms in sourdoughs (Olojede *et al*.2023).

3.5 Effect of Feed Pump Rate on Total Titratable Acid (TTA) and pH

Spray drying of sourdough can lead to a slight increase in pH due to the loss of acidic compounds. The variation of the TTA and the pH of the spray-dried sourdough due to an increment in FPR is shown in Figure 5.

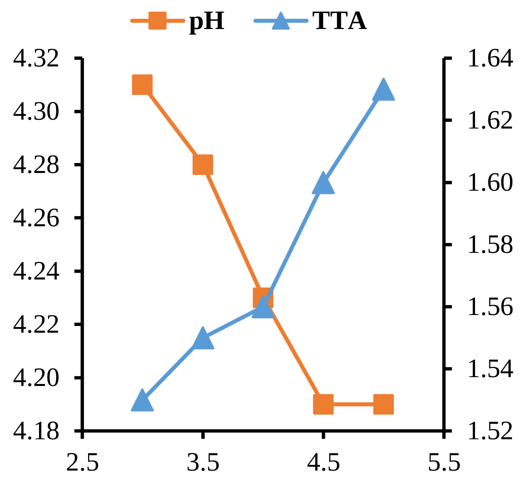

Figure 5. Effect of Feed Pump Rate on pH and TTA

From Figure 5, an increase in FPR reduces the pH, but an increase for TTA. Even though the changes in pH and TTA were small, it did show that an increase in FPR might have reduced the severity of the drying air temperature, which reduced the disintegration of the acidic compounds present in the sourdough. The pH and the TTA ranged from about 4.3 to 4. 19 and 1.5 to 1.6 ml respectively. Caglar *et al*. (2021) reported similar results in pH from their investigation of a sourdough spray drying. Reidzane *et al*. (2021) stated that the pH of a well-developed sourdough is from 3.5 to 4.3. The pH range obtained in this study is within this range.

3.6 Effect of Feed Pump Rate on Bulk Density

The effect of flow rate on bulk density is shown in Figure 6. It can be seen in Figure 6 that the bulk density increases, with an increase in the feed pump rate (FPR). Chegini and Ghobadian (2005), and Padma *et al.* (2022) reported similar observation. The increase in the feed pump rate caused inadequate drying of the sourdough powder, which increased the moisture content of the powder and hence the bulk density (Jain *et al.*, 2017).

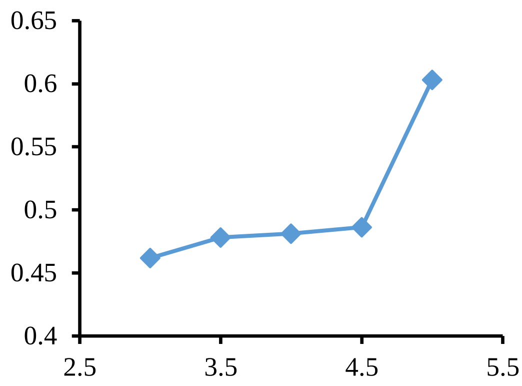

Figure 6. Effect of Feed Pump Rate on Bulk Density

In Figure 6, the bulk density of spray-dried sourdough varied from about .0.46 to 0.60 g/ml. A bulk density of 450 to 700 kg/ m^3 for spray-dried sourdough, was reported by Caglar *et al*.(2021).

4. CONCLUSIONS

Dehydration of sourdough into powder form has several advantages including longer shelf life, constant product quality, and lower transportation cost. The effect of feed pump rate on the spray drying of acha sourdough was investigated. Results of evaluation of the response parameters showed that the feed pump rate was a critical process parameter in the spray drying of the acha sourdough. The highest powder yield was 50% at a feed pump rate of 4 Hz. Beyond this feed pump rate, the powder yield reduces. The exit air temperature and pH responded negatively, with an increase in feed pump rate. The thermal efficiency, evaporation rate, moisture content, microbial counts, and bulk density, varied positively with an increase in feed pump rate.

From the analyses results of moisture content, pH, total titratable acid, and microbial counts, the spray drying process produced dehydrated acha sourdoughs with standard functional properties. These show that spray drying feed rate can be manipulated to produce acha sourdough for the production of gluten-free baked foods. Nevertheless, a holistic investigation is needed to optimize the entire process parameters, for a tradeoff for low moisture content and high powder yield.

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NOTATION

CFU = Colony forming unit
FPR = Feed pump rate (%)
EAT = Exit air temperature (℃)
RH = Evaporation rate (%)
TE = Thermal efficiency (%)
ER = Evaporation rate (g/min)
PY = Powder yield (%)
MC = Moisture content (%)

6. REFERENCES

Albagli, G., Schwartz, I. M., Amaral, P. F. F., Ferreira, T. F. and Finotelli, P. V. (2021). How dried Sourdough Starters can Enable and Spread the Use of Sourdough Bread. *LWT- Food Science and Technology*, 149,111888.

Association of Official Analytical Chemists (AOAC) (2000). Official Methods of Analysis of the Association of Official Analytical Chemists, seventeenth edn. Gaithersburg, MD: Association of Official Analytical Chemists

Atalar, I. and Dervisoglu, M. (2014). Optimization of Spray Drying Process Parameters for Kefir Powder Using Response Surface Methodology. LWT- Food Science and Technology, 60(2): 751-757

Babatuyi, C. Y., Adisa, A. M., Temitope, C. I. and Enujiugha, V. N. (2023). The Variations in Chemical Composition, Antioxidant Capacity, and Pasting Properties of Fonio Sourdoughs. DYSONA– Applied Science, 4: 51-6.

Behboudi-Jobbehdar, S., Soukoulis, C., Yonekura, I. and Fisk, I. (2013). Optimization of Spray-Drying Process Conditions for the Production of Maximally Viable Microencapsulated L. acidophilus. *Drying Technology*, 31(11): 1274-1283,

Caglar, N., Ermis, E. and Durak, M.Z. (2021). Spray-dried and Freeze-dried Sourdough Powders: Properties and Evaluation of their Use in Breadmaking. *Journal of Food Engineering*, 292: 110355.

Calvert, M.D.; Madden, A.A.; Nichols, L.M.; Haddad, N.M.; Lahne, J.; Dunn, R.R. and McKenney, E.A. (2021). A Review of Sourdough Starters: Ecology, Practices, and Sensory Quality with Applications for Baking and Recommendations for Future Research. *PeerJ*, 9: e11389.

Chegini, G.R. and Ghobadian, B. (2005). Effect of Spray-drying Conditions on Physical Properties of Orange Juice Powder. *Drying Technology*, 23 (3): 657–668.

De Vuyst, L., S. Van Kerrebroeck, S. and Leroy, F. (2017). Microbial Ecology and Process Technology of Sourdough Fermentation.

Advances in Applied Microbiology, 100: 49–160.

De vuyst. L., Comasio, A. and Van Kerrebroeck, S. (2021). Sourdough Production: Fermentation Strategies, Microbial Ecology, and Use of Non-flour Ingredients. *Critical Reviews in Food Science and Nutrition*, 63(15): 2447-2479.

De Vuyst, L., Comasio, A. and Van Kerrebroeck, S. (2023). Sourdough Production: Fermentation Strategies, Microbial Ecology, and Use of Non-flour Ingredients. *Critial Reviews in Food Science and Nutrition*, 63(15): 2447–2479.

Edema, M. O., Emmambux, M. N. and Taylor, J. R. N. (2013). Improvement of Fonio Dough Properties Through Starch Modification by Sourdough Fermentation. *Starch/Starke*, 00: 1-8.

Golman, B. and Julklang, W. (2014). Simulation of Exhaust Gas Heat Recovery from a Spray Dryer. *Applied Thermal Engineering*, 73(1): 899–913.

Hong, P.V.C., Tan, H.D., Thanh, P.T.T., Cang, M.H., Don, D.L and Thien, L.T. (2021). Spray Drying Conditions for Protein Hydrolysate of Crocodile Meat. *Food Research*, 5 (1): 140– 148.

Huang, S., Vignolles, M. L., Chen, X. D., Le Loir, Y., Jan, G., Schuck, P. and Jeantet, R. (2017). Spray Drying of Probiotics and Other Food Grade Bacteria: a Review. *Trends in Food Science & Technology*, 63: 1-17.

Ilha, E. C., Da Silva, T., Lorenz, J. G., De Oliveira Rocha, G. and Sant'Anna, E. S. (2015). *Lactobacillus paracasei* Isolated from Grape Sourdough: Acid, Bile, Salt, and Heat Tolerance after Spray Drying with Skim Milk and Cheese Whey. *European Food Research and Technology*, 240(5): 977–984.

Jain, M. S., Lohare, G. B., Bari, M M., Chavan, R. B., Barhate, S.D. and Shah, C. B. (2012). Spray Drying in Pharmaceutical Industry: a Review. Research Journal of Pharmaceutical Dosage Forms and Technology, 4(2): 74-79.

Jain, P., Gupta, A.K., Pathak, M. K. and Khanna, N. (2017). Effect of Process Conditions on the Physicochemical Properties of Fermented Beet Root Juice Powder Produced by Spray Drying. *International Journal of Current Microbiology and Applied Sciences*, 6(12): 4209-4216.

Khem, S., Woo, M.W., Small, D.M., Chen, X.D. and May, B.K. (2015). Agent Selection and Protective Effects During Single Droplet Drying Of Bacteria. *Food Chemistry*, 166: 206–214.

Liu, B., Fu, N., Woo, M. W. and Chen, X. D. (2018). Heat Stability of *Lactobacillus Rhamnosus* GG and its Cellular Membrane during Droplet Drying and Heat Treatment. *Food Research International*, 112: 56–65.

Luti, S., Mazzoli, L., Ramazzotti, M., Galli, V., Venturi, M., Marino, G., Lihman, M., Guerrini, S., Granchi, L., Paolo, P. and Pazzagli, L. (2020). Antioxidant and Anti-Inflammatory Properties of Sourdoughs Containing Selected *Lactobacilli* Strains are retained in Breads. *Food Chemistry*, 322: 126710.

Mohd Roby, B. H., Muhialdin, B. J., Abadl, M. M. T., Mat Nor, N. A., Marzlan, A. A., lim, S. A. H., Mustapha, N. A. and Meor Hussin, A. S. (2020). Physical Properties, Storage Stability, and Consumer Acceptability for Sourdough Bread Produced Using Encapsulated Kombucha Sourdough Starter Culture. *Journal of Food Science*, 85(8): 2286-2295.

Mantzourani, I., Terpou, A., Alexopoulos, A., Bezirtzoglou, E. and Plessas, S. (2019). Assessment of Ready-To-Use Freeze-Dried Immobilized Biocatalysts as Innovative Starter Cultures In Sourdough Bread Making. *Foods*, 8(1): 40.

Moreira, M. T. C., Martins, E., Perrone, I. T., De Freitas, R., Queiroz, L.S. and De Carvalho, A. F. (2021). Challenges associated with Spray Drying of Lactic Acid Bacteria: Understanding Cell Viability Loss. *Comprehensive Reviews in Food Science and Food Safety*, 20: 3267–3283.

Olojede, A. O., Oahimire, I. O., Gbande, J.I., Osondu-Igbokwe, A. D., Thomas, R. M., Olojede., D.S. and Banwo, K., (2023). Evaluation of Acha Flour in the Production of Gluten-Free Sourdough Cookies. *International Journal of Food Science and Technology*, 58: 3244–32501.

Padma, M., Jagannadha Rao, P. V. K., Edukondalu, L., Aparna, K. and Ravi Bab, G. (2022). The Effects of Spray Drying Conditions on Moisture Content, Water Activity, Bulk Density, and Tapped Density of Rice Milk Powder. *International Journal of Environment and Climate Change*, 12(11): 3575-3590.

Peighambardoust, S. H., Golshan, T. A., and Hesari, J. (2011). Application of Spray Drying for

Preservation of Lactic Acid Starter Cultures: a Review. *Trends in Food Science & Technology*, 22(5): 215-224.

Pinon-Balderrama, C., Leyva-Porras, C., Espinosa-Solís, V., Terán-Figueroa, Y., Álvarez-Salas, C. and Saavedra-Leos, M. Z. (2020). Encapsulation of Active Ingredients in Food Industry by Spray-Drying and Nano Spray-drying Technologies. *Processes*, 8(8): 889

Reale, A., Di Renzo, T., Preziuso, M., Panfili, G., Cipriano, L. and Messia, M.C. (2019). Stabilization of Sourdough Starter by Spray Drying Technique: New Breadmaking Perspective. *Lebensmittel-LWT- Food Science and Technology*, 99: 468–475.

Reidzane, S., Kruma, Z., Kazantseva, J., Traksmaa, A. and Klava, D. (2021). Determination of Technological Parameters and Characterization of Microbiota of the Spontaneous Sourdough Fermentation of Hull-Less Barley. *Foods*, 10: 2253.

Santos, D., Maurício, A. C., Sencadas, V., Santos, J. D., Fernandes, M. H. and Gomes, P. S. (2018). Spray drying: An overview. In Biomaterials - physics and chemistry (New Edition). InTech.

Schutyser, M. A. I., Both, E. M., Siemons, I., Vaessen, E. M. J. and Zhang, L. (2019). Gaining Insight on Spray Drying Behavior of Goods Via Single Droplet Drying Analyses. *Drying Technology*, 37(5): 525-534.

Stefanello, R. F., Nabeshima, E. H., Lamanaka, B. T., Ludwig, A., Fries, L. L. M., Bernardi, A. O. and Copetti, M. V. (2019). Survival and stability of *Lactobacillus Fermentum* and *Wickerhamomyces Anomalus* strains upon Lyophilisation with Different Cryoprotectant Agents. *Food Research International*, 115: 90-94.

Tafti, A. G., Peighardoust, S. H., Behnam, F., Bahrami, A., Aghagholizadeh, R., Ghamari, M. and Rafat, S. A. (2013a). Effects of Spray-Dried Sourdough on Flour Characteristics and Rheological Properties of Dough. *Czech Journal of Food Sciences*, 31(4): 361 367.

Tafti, a. G., Peighambardoust, S. H., Hesari, J., Bahrami, A. and Bonab, E. S. (2013b). Physico-Chemical and Functional Properties of Spray-Dried Sourdough in Breadmaking. *Food Science & Technology International*, 19(3): 271-278.

Tan, L. W., Ibrahim, M. N., Kamil, R. and Taip, F. S. (2011). Empirical Modeling for Spray Drying Process of Sticky and Non-Sticky Products. *Procedia Food Science*, 1: 690 – 69.

Tan, D. T., Poh, P. E. and Chin, S. K. (2018). Microorganism Preservation By Convective Air-Drying: a Review. *Drying Technology*, 36(7): 764-779.