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Non-Destructive In-Process Quality Evaluation Of Plant-Sourced Food During Drying

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Abstract. Plant-sourced food has a crucial role in the human food supply as the source of calories and many valuable micronutrient compounds that enhance a balanced and healthy lifestyle. However, a portion of food intended for human consumption produced globally become wastage per year because of a lack of proper processing and preservation technologies. Drying is one of the broadly utilised preservation technologies in plant-sourced food. Most drying studies focused on post-process evaluation on product quality; meanwhile, monitoring and controlling amid the drying process (in-process) is essential because these activities can improve the drying condition and optimise the end product's quality. Furthermore, the non-destructive inspection method is essential in developing smart food processing units and can be more efficient, rapid, reduced sample waste, and environmentally friendly than traditional inspection methods. The authors also discuss the overview of quality parameters investigated during plant-sourced food drying with in-process and non-destructive quality evaluation techniques. Finally, the authors also discuss the prospects and challenges of the real-time and non-destructive quality evaluation application.

1. Introduction

This paper aims to review studies related to the importance and trend in plant-sourced food's non-destructive in-process quality assessment amid drying. This paper also discusses why it is essential in the development of plant-sourced food smart drying processing units.

The United Nations projects the world population to feed to reach 9.8 billion by 2050 [1]. Thus, plant-sourced food has a vital role in the human food supply as the source of calories and many valuable micronutrient compounds that enhance a balanced and healthy lifestyle [2].

However, food waste harms the sustainability of this food source. The Food and Agriculture Organization of the United Nations (FAO) [3] reported that one-third of food intended for human consumption produced globally become wastage per year. That is due to a lack of proper processing and preservation technologies [4]. Therefore, proper food processing is critical.

Drying is one of the widely used preservation technologies in plant-sourced food. It extends the plant-based product's shelf life regardless of the season, reduces weight and volume for more

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convenient transportation and reduces microorganism's load; furthermore, it inactivates the enzymes of the produce. However, some drawbacks are available, such as undesirable changes in a dried commodity's physicochemical, biochemical, and sensory properties [5].

Consumers are becoming more health-conscious, inseparable from wholesome food [6,7]. However, consumer trust crises are due to frequent frauds and adulteration in food; therefore, food safety and quality research are essential [8].

Most drying studies focused on evaluating product quality after the process (post-process) [5]. However, the quality evaluation under the black-box approach hardly achieves high-quality products because this approach does not account for the dynamic changes of product attributes throughout food processing [9]. Meanwhile, continuously monitoring and controlling the drying process through the process (in-process) is essential in process control because these activities can improve drying condition and end product's quality [10].

The production of food that complies with consumers' demand for high-quality food requires a comprehensive quality and safety inspection that cover all batches of food during processing. Kessler in [11] classifies the process analysis into a) offline, samples are taken from the production line and transported to a testing laboratory; b) atline, sampling is done manually or semi-automatically and transported to a testing laboratory which is located closer to the process line than that of with offline analysis; c) online, all the steps from sampling, testing to evaluation result are automated. In addition, online inspection allows immediate corrective action in the process control system; d) inline. The analysis equipment is fully installed above the material stream to have no sampling or preparation.

The conventional quality evaluation is beneficial for complex parameter analysis but has several drawbacks: time consumption, subjectivity, labour intensity, sample destruction and inconsistency [12]. In addition, some investigations require chemical reagent -which is pricy and the waste often harmful for humans and the environment-, highly skilled labours and relevant sophisticated instruments [6]. However, Alander et al. [6] and Guidetti et al. [13] found that non-destructive quality evaluation techniques are more efficient, rapid, reduced sample waste, and environmentally friendly than traditional inspection methods.

2. Quality Parameters Investigated During Plant-Sourced Food Drying With In-Process and Non-Destructive Quality Evaluation Techniques

Chemometrics uses the principles of mathematics and statistics to convert chemical data into useful information for decision making [14]. Many drying studies combined chemometrics with several technologies. Each technology delivers advantages in food quality evaluation. NIR is a real-time, non-invasive, dependable, and appropriate method to monitor the physicochemical properties of food during processing [15]. Developed computer vision-based inspection method has substituted manual inspection [16]. Hyperspectral imaging system (HSI) combines spectroscopy and computer vision. Food researchers and manufacturers have used HSI to monitor the quality and safety of food for many years [12]. Bonah et al. [7] utilised an electronic nose to detect and classify food-borne pathogen bacteria based on volatile compounds produced by the microorganisms. This methodology offered online, rapid, non-destructive analysis, and with less chemical required.

Moscetti et al. [17] investigated organic carrot var. Romance which was hot-water blanched and then hot air dried with a one-hour interval of observation at 40ºC. The researchers combined chemometrics techniques (e.g., partial least squares) with NIR spectroscopy at 1100–2300 nm. They developed a regression model with good to excellent linear fit for water activity, moisture content, total carotenoid content, lightness, and hue angle for unblanched and blanched samples. However, the model was inadequate for the soluble solid content parameter.

Rahman et al. [18] studied convective dried Granny Smith apple (with different thickness and drying temperature) for its cellular level moisture content, equivalent cell diameter, porosity, and cell rupture at every 30 minutes of observation. The investigators applied X-ray micro-tomography and suggested that high drying temperature increased the pore formation and cell rupture but reduced the

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shrinkage. In addition, this study revealed the cellular water distribution of samples over the time of drying.

Crichton et al. [19] used hyperspectral techniques (400-1000 nm) with partial least square regression (PLSR) model to predict moisture content and colour of raw and pre-treated apple slices (var. variety Golden Delicious) with an interval of 30 minutes of measurement. They found that HSI is the potential for online moisture content and colour inspection during oven drying. Furthermore, computer vision (as part of HSI) is feasible as a tool for online shrinkage area inspection in hot air drying of apple slices [20].

There are several other studies on apple drying. Nadian et al. [21] investigated moisture loss and colour changes on apples (var. Golden Delicious) at different drying temperatures, air velocity and thickness during hot air drying. The investigators used a multilayer perceptron (MLP) artificial neural network (ANN). They found that: drying temperature and sample thickness affected the colour changes; Samples colour as a function of moisture content has a high value of correlation, and MLP ANN helps monitor colour and moisture content on apple slices during drying. Aghilinategh et al. [22] measured or calculated drying rate, drying time, normalised colour, and total colour difference on intermittent microwave convective air-dried apple (*Malus domestica*) by utilizing image processing. They concluded that microwave power and pulse ratio (PR) are the most affecting factor on lightness and colour change.

Pu and Sun [23] observed the moisture content of mango slices over different times of microwave-vacuum drying. They combined PLS with two line-scan reflectance hyperspectral imaging systems (HSI): Vis-NIR (400– 1000 nm) and NIR (880–1720 nm). This study showed that HSI is capable of estimating moisture content non-invasively and quickly. López [24] agreed with the result. The investigator stated that post-harvest processing could use VIS-NIR spectroscopy to monitor fruit (mangoes) safety and quality in both offline and online modes.

HSI has a profound benefit over conventional NIR spectroscopy. HSI gives a full spectrum for each hypercube's pixel. Meanwhile, the latter only provides an average spectrum for the whole sample batch [25]. HSI developed an algorithm during the drying process to develop smart food drying processing units [26].

Behroozi Khazaei and colleagues [27] investigated seedless sultana grapes (*Vitis vinifera* L.) for their moisture content and shrinkage at an interval of 20 minutes with the treatment of different drying temperatures and air velocity. They concluded that applied machine vision with chemometrics of artificial neural networks could predict the moisture content of grapes.

Amjad et al. [28] observed moisture content and colour of potato slices (*Solanum tuberosum* L. var. Anuschka) with different drying temperatures and sample thickness during hot air drying at an interval of 30 minutes of measurement. The researchers found that HSI is functional equipment for non-invasive detection, and PLS gave the most suitable model. Other research on tuber drying used NIR and mid-infrared (MIR) hyperspectral techniques combined with several multivariate models to predict the moisture content of potato (var. Rooster and Melody) and sweet potato (var. Covington and Evangeline) [29]. Nguyen et al. [30] studied the moisture profile of potatoes and maltodextrin. They dried samples in a tunnel dryer with different temperature treatments. The investigators observed the moisture profile by utilising a magnetic resonance image (MRI). This study suggested that temperature affected the dry layer formation of maltodextrins, but the potato and glass transition temperature does not drive the dry layer formation during drying.

Heo et al. [31] steamed and dried purple sweet potato at 55 °C at different drying times of 0, 2, 4, 6, 8, or 10 h. They utilized the partial least squares regression (PLSR) model to project the moisture content based on hyperspectral imaging data analysis. The investigator found that the model utilised five wavelengths, which affected the PLSR model the most, provided a more accurate prediction than that of the model that used the full spectrum wavelength.

Lewis et al. [32,33] monitored plant production's moisture content (grain and oilseed products, peanut kernel/ shelled peanuts, and peanut pods/ unshelled pods) real-timely and non-invasively using microwave moisture sensors. The studies concluded that microwave moisture content sensor is an effective and efficient real-time and non-destructive inspection tool.

Xie et al. [34] utilised a visual-NIR hyperspectral imaging system. The wavelength to observe the chromaticity of tea leaves during hot drying is 380–1030 nm. They suggested that the tool can determine the colour properties and category of tea leaves non-invasively and objectively.

2.1. Real-Time and Non-Destructive Quality Evaluation On Plant-Sourced Food Drying: Prospective application

Post-harvest loss or waste also occur in food manufacturing. However, food waste harms not only food security but also economics [35]. Bharat Helkar and Sahoo [36] defined food waste or by-products are edible food products expected for human consumption but have instead been disposed of or lost.

The food industry often demands many specific resources, resulting in many substandard products and more waste productions. On the other hand, small scale industries -mostly limited capital- demand affordable solutions that the scientific community can deliver [9]. On the other side, small and medium-sized enterprises contribute almost two-third of global labour [37].

Real-time quality control during drying may prevent over-drying and thus reduce energy [38]. In addition, real-time and non-destructive techniques may reduce waste during food processing [39].

One of the strategies to implement real-time and non-destructive quality inspection and control in the drying sector is smart/ intelligent drying [40]. Smart drying is a drying process that involves a dryer, a sensor to monitor the control variables that corresponding to the quality of the product, translator, and control systems to manage the drying condition inline to enhance the product quality and at the same time consider the environmental sustainability [41].

2.2. Real-Time and Non-Destructive Quality Evaluation On Plant-Sourced Food Drying: Challenges

Despite the potentials of real-time and non-destructive quality evaluation on plant-sourced food drying, it also comes with challenges. Li et al. [10] suggested that the machine learning community's major drawback is developing simple maintenance systems for actual industrial deployment and not needing machine learning experts to regulate the learning parameters for optimal performance manually. Furthermore, they elaborated that novel sensing technologies (e.g., computer vision, HSI, NIR and dielectric spectroscopy, nuclear magnetic resonance, electronic nose) may not apply to a particular analytical technology inline analyser. The limitation is that inline methods must enable the measurement without removing the sample from the drying system.

3. Conclusions

Plant-sourced food is essential to a healthy and balanced lifestyle as a calorie source and other functional compounds. However, plant-sourced food is considered perishable food due to its high content of moisture. Here is where drying technology is essential. This technology allows plant-sourced food to have prolonged shelf-life regardless of the season, less weight and volume for simpler distribution. The drying method also affects the quality of plant-sourced food (physicochemical, functional, and sensory properties). The studies on plant-sourced food during drying in a real-time and non-destructive manner offers a better understanding of the drying process while enhancing other benefits such as reduced food waste, labour, and reagent.

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