PROSPECTS AND IMPACTS OF INNOVATIVE TECHNOLOGY FOR PROCESSING NATURAL FRUIT RAW MATERIALS INTO POWDER FORM

Andrii Makarenko*, Tetiana Turchyna, Lesia Avdieieva
Institute of Engineering Thermophysics, National Academy of Sciences of Ukraine, Kyiv, Ukraine
**Corresponding author: tbds_ittf@ukr.net*

The wide range of Ukrainian fruit raw materials as a source of valuable bioactive substances should be processed into powdered products for health, therapeutic, and dietary nutrition. Processing whole fruits enriches powdered products with their own bioactive substances, including vitamins, minerals, pectins, dietary fibers, organic acids, phytoestrogens, and many others. Such products not only serve as food but also have health-promoting functions, such as boosting immunity and cleansing the body of dangerous heavy metals or chemical elements absorbed from air, water, or food. Therefore, powdered products from fresh fruit raw materials are strategically important for the health improvement of our nation.

The innovative production technology consists of two stages: 1. Preparation of raw materials through hydrodynamic treatment with a biopolymer additive, creating a structured suspension; 2. Drying of the suspended material using a disc atomizer in a stream of heated heat carrier to obtain a fine-dispersed powder.

The introduction of biopolymer additives during homogenization improves the rheological properties of the fruit masses and achieves several benefits: 1. Preservation and stabilization of bonds during fruit disintegration; 2. Uniform distribution of particles in the liquid system, preventing delamination; 3. Stabilization of pH at ≥4-5, reducing adhesive issues during drying; 4. Improved structural properties for high powder yield and quality; 5. Microencapsulation of thermolabile bioactive substances, ensuring high preservation, minimal moisture, and a storage period of over 1 year.

Keywords: fruit raw material, structured suspension, spray drying, powder

DOI: 10.24263/EDSD-2024-6-41

Received 26.04.2024
Received in revised form 12.10.2024
Accepted 05.11.2024

Introduction

In the context of the war in Ukraine and mass migration of displaced persons with children, there is a growing demand for quick-recovery products with high nutritional and biological value. Such products enable the preparation of cold or hot beverages, hot dishes, or desserts, even in mobile conditions, with only a sachet of high-quality powdered product made from domestically sourced natural fruit raw materials and water at hand.

Ukraine has always been renowned for its abundant harvests of fruits, vegetables, and berries. Unfortunately, a significant portion of this crucial raw material resource is lost annually due to irrational usage, transportation issues, processing, and storage (Kernasyuk Y., 2022).

Fruit and berry, as well as fruit and vegetable, raw materials are a source of numerous beneficial substances: vitamins, minerals, pectins, dietary fibers, organic acids, phytoestrogens, and many others (Telezhenko L.N., 2004; Flaumenbaum B.L., 2006; Dyakonova A.K., 2006). Their composition is characterized by a high content of fiber, which is capable of binding heavy metal radicals or chemical toxins absorbed by the human body from air, water, and food, thereby performing a healing and antioxidant function. Therefore, from the perspective of improving the health of our nation, the processing of the new harvest into powdered form of quickly recoverable products (Mujumdar, A.S. (Ed.), 2006; Dolinsky, A., 2000; Sloan E., 2018; Skopenko N., 2013) is relevant, promising, and strategically important for our country.

Materials and Methods

The analysis of the processes of forming structured heterogeneous systems from diverse fruit raw materials was conducted based on the results of experimental studies of the drying process in the "drop-vapor-gas environment" system and on experimental and pilot-scale spray dryers at the Institute of Engineering Thermophysics of the National Academy of Sciences of Ukraine. Research samples were prepared using fruit compositions with added dextrin-containing or protein additives, such as whey protein concentrate (WPC), which were introduced during their preliminary discrete-pulsed input of energy (DPIE) treatment in cylindrical-type rotary-pulsation apparatus (RPA) (Dolinsky A.A., 2015; Turchyna T.Ya., 2024).

Results and Discussion

Numerous scientific and experimental studies on the processing processes of fruits from various plant raw materials into powdered form, conducted at the Institute of Engineering Thermophysics of the National Academy of Sciences of Ukraine, have shown that obtaining high-quality powders from them through spray drying is often impossible without biopolymer additives (Bindu Bazaria, 2014; Gong, Z., 2018; Dolinsky A.A., 2015). Most fruit masses, after grinding and homogenization, are found to be imperfect objects for spray drying in many parameters (Sharkova N.O., 2017; Turchyna T.Ya., 2024).

First and foremost, they are characterized by abnormal rheological properties and a tendency to stratify, complicating the process of forming spherical droplets at the moment of detachment from the edge of the disc atomizer in the spray dryer. Additionally, the microstructural analysis revealed a wide range of particle and fragment sizes of insoluble fractions in the composition of experimental batches of suspensions, purees, or pastes, further complicating the formation of a homogeneous spray cone in the dryer and thereby increasing the risk of large, under-dried droplets adhering to the chamber walls.

The instability of pH indicators (within ≤ 4.0) in dispersed systems from fruit and berry or fruit and vegetable raw materials leads to increased thermoplasticity of the powder and a higher likelihood of adhesive deposits forming in the spray dryer chamber. Furthermore, in some cases, the significant content of organic acids in certain types of raw materials (such as tomatoes, apricots, cherries, plums, strawberries, raspberries, and currants) weakens their structural-forming ability necessary for forming a stronger and more monolithic particle structure during spray drying, which is essential for better flowability.

Experimentally, it has been determined that to ensure stable drying process conditions in the experimental spray dryer RC-1.3 (Dolinsky A.A., 2015), a high degree of particle dispersion of insoluble fractions in the liquid heterogeneous system of fruit raw materials is necessary, with a maximum particle size $\delta_{max} \leq 100$-150 micrometers. However, even achieving the desired degree of dispersion of the liquid fruit system without additional introduction of biopolymer additives is not a guarantee of creating the necessary conditions for feeding the system into the dryer and obtaining a dispersed powder without adhesive deposits (Turchyna T.Ya., 2024).

During the disruption of structural systems of fruit-berry and fruit-vegetable raw materials in RPA processing, dispersion and transition to a soluble state of substances occur, including those prone to gel and draglet formation (such as pectins, cellulose, etc.). Increasing the duration of the homogenization process to achieve the desired degree of particle dispersion in fruit liquid systems does not always positively affect their rheological properties. Dispersed systems with a high content of complex polysaccharides (tomatoes, raspberries, strawberries, currants, mushrooms) gradually turn into a strong gel over time, making them unsuitable for pump feeding into the dryer (Dyakonova A.K., 2006; Sharkova N.O., 2017). Experimentally, it has been proven that dispersion and homogenization of fresh plant raw materials to form stable homogeneous systems are advisable to conduct in apparatuses implementing the DPIE method, which can ensure the desired degree of dispersion in the shortest time (Turchyna T.Ya., 2024).

To enhance the structural-forming properties of liquid dispersed systems, we investigated the effect of several biopolymer products in the form of additives: dextrin-containing or animal-derived proteins, including WPC. Among the dextrin-containing products for fruit compositions, we selected domestically produced fully hydrolyzed starch syrup (an analogue of foreign maltodextrins and cyclodextrins) – a corn processing product, a biopolymer consisting of glucose, maltose, and dextrins (55-65%). According to data (Dolinsky A.A., 2015), it is the carbohydrate composition of the starch syrup and the ratio of its components that determines the increased heat resistance of the formed fruit compositions as objects of spray drying.

For some fruit compositions with a high content of organic acids (tomatoes, strawberries, raspberries, cherries), the introduction of starch syrup with pH≥4.6 in an amount of up to 50% of the total dry matter mass was insufficient to obtain a strong particle structure, increase their heat resistance, and reduce adhesive deposits in the spray dryer chamber. In this case, proteins from WPC were effectively used in combination with it, which, together with starch syrup, were introduced during the DPIE processing of raw materials in RPA of the BGT model, a photo of which is shown in Figure 1 (a).

Figure 1 depicts experimental-industrial samples of cylindrical-type rotary-pulsation apparatuses developed at the Institute of Engineering Thermophysics of the National Academy of Sciences of Ukraine (IET NASU). In the research and development of rational process parameters for the DPIE treatment of fruit purees of strawberries, raspberries, apricots with carrots, cherries, blueberries, and tomatoes to achieve the desired degree of particle dispersion of insoluble fractions before feeding into the spray dryer, these devices operating in recirculation mode showed the best results (Dolinsky A.A., 2015). Comparative technical specifications of two types of RPA are shown in Table 1.

To enhance the structural-forming potential during spray drying and neutralize the acidic environment of "Red-cheek" apricots (pitted), carrot (15% of the total dry matter) was used. To achieve the desired level of dispersion of the apricot-carrot composition in the shortest time possible (3-5 minutes), a lower-power RPA of the BG-3 model (Figure 1, b) was used, which proved to be sufficient. The incorporation of corn starch syrup in the raw material improved the rheological properties of the composition, increased and stabilized the pH level at 4.3, structured within the desired degree of particle dispersion, and provided resistance to delamination throughout the processing until it was fed into the spray dryer (Turchyna T.Ya., 2024).

a)

b)

Figure 1. Rotary-pulsation apparatuses of cylindrical type developed at the IET NASU: a) model BGT; b) model BG-3

Table 1. Technical specifications of the RPA

	BGT	BG-3
Productivity, kg/h	500-800	400-500
Power, kW	11.0	5.5
Number of stators/rotors	2/1	
Rotor rotation frequency, rpm	3000	

Research on the spray drying process of these fruit suspensions, conducted on the experimental spray dryer RC-1 with a productivity of 10 kg/h based on evaporated moisture at temperature conditions of T_{inlet}/T_{outlet} = 180°C/90°C, showed excellent results in terms of quality and powder yield. In the absence of adhesive deposits in the dryer chamber, the powder yield was maximized, reaching up to 92-94%. The obtained strawberry and raspberry powders, containing starch syrup and WPC as structuring additives, and apricot-carrot powders with syrup, exhibited high organoleptic characteristics of both the dry powder and the reconstituted product, resembling fresh raw materials, with minimal moisture content (2.5-3.5%), high solubility index, flowability, and a significant shelf life of over 2 years.

The positive effects obtained during the DPIE treatment of fruit pulps with added biopolymer additives and in the subsequent spray drying of already structured heterogeneous systems were found to be interconnected processes of mass transfer, physicochemical transformations, and transformations at the micro- and nanoscale levels, occurring under the action of discrete-pulse energy input mechanisms.

Therefore, the introduction of biopolymer additives during DPIE treatment of fruit pulps allowed to:

- Achieve the desired degree of particle dispersion of non-soluble fractions of fruit heterogeneous systems in the shortest time (3-5 minutes) (Turchina T.Ya., 2024).
- Improve their rheological properties (Sharkova N.O., 2017).
- Achieve uniform distribution of micro- and nanoparticles of non-soluble fractions in the volume of the dispersion medium, enhanced by dextrin-containing additives and/or WPC, which acts as a surfactant, thus achieving the effect of structuring a complex fruit system (Dolinsky A.A., 2015).
- Provide liquid dispersion systems with stability against delamination due to the cushioning properties of dispersion medium nanoparticles.
- Stabilize pH levels at ≥4.3-5.5.
- Achieve a preservation effect for newly formed open bonds of thermo- and xerolabile biologically active substances in fresh fruit raw materials (Dolinsky A.A., 2005; Dyakonova A.K., 2006).
- Achieve microencapsulation effect of thermolabile biologically active components within micron-sized particles during spray drying, as a result of effective control over shaping and structuring processes during dehydration of such materials (Turchina T.Ya., 2024; Xiao Dong Cheng, 2004).

Therefore, the process of converting fresh fruit-berry and fruit-vegetable raw materials into powder form using innovative technology includes the following main stages (Dolinsky, A., 2000; Dolinsky A. A., 2015):

- Preparation of raw materials for drying, short-term exposure during DPIE treatment with the addition of biopolymer additives until obtaining a structured and stabilized heterogeneous system.
- Drying of the sprayed suspension using a disk atomizer in a stream of heated heat carrier to obtain a microencapsulated form of dispersed powder with a long shelf life.

Numerous experimental and industrial tests have proven that obtaining high-quality fruit-vegetable, fruit-berry, or mushroom powders for long-term storage is possible exclusively under the conditions of such an approach to processing fruit raw materials with mandatory use of dextrin-containing or protein additives as carriers and/or encapsulating agents (Dolinsky A. A., 2015; Patent for invention No. 118426 UA; Bindu Bazaria, 2016; Gong, Z., 2018; Emilia Janiszewska, 2014). Powders obtained using the innovative technology from fruit raw materials due to the increased content of bioavailable substances with medicinal, immunostimulating, or antioxidant properties acquire characteristics of medicinal, dietary, or health-improving products.

High yields of fruits, vegetables, berries, the availability of corn starch syrup (instead of expensive maltodextrins and cyclodextrins), and whey protein concentrate provide opportunities for implementing this innovative technology in dairy processing enterprises equipped with spray dryers. Industrial production of powdered products from fresh fruit raw materials will expand the range of high-quality instant restorative products available to all segments of the population and necessary for the health improvement of the nation.

Conclusions

The analysis of experimental studies has shown the potential of implementing innovative technology for processing fresh fruit raw materials into restorative powdered food products. The use of cylindrical-type rotary-pulsation apparatus with implementation of DPIE mechanisms during dispersion and homogenization of fruit raw material with added biopolymer additives at the preparation stage for spray drying contributes to the stabilization and structuring of the formed liquid dispersion systems and results in a range of positive effects. The main of which include the elevation and stabilization of pH levels at ≥4, crucial for reducing the risk of adhesion phenomena in the spray dryer chamber, and obtaining a microencapsulated form of high-quality powders capable of preserving their organoleptic and bulk properties for over 2 years and recovering with the reproduction of characteristics of the utilized fresh raw material.

Conflict of interest

The authors state no conflict of interest.

References

Bazaria, B., & Kumar, P. (2016). Effect of whey protein concentrate as drying aid and drying parameters on physicochemical and functional properties of spray dried beetroot juice concentrate. *Food Bioscience*, 14, 21-27.

Cheng, X. D. (2004). Heat-Mass Transfer and structure formation during drying of single food droplets. *Drying Technology*, 22(1-2), 179-190.

Dolinsky, A., Maletskaya K., & Snezhkin Y. (2000). Fruit and vegetable powders production technology on the bases of spray and convective drying methods. *Drying Technology*, 18(3), 747–758.

Dolinsky, A. A., & Maletskaya, K. D. (2015). *Spray drying. In 2 volumes. Volume 2. Heat technologies and equipment for obtaining powdered materials*. Kiev: Akademperiodika.

Dolinsky, A. A., & Basok, B. I. (2005). Nanoscale effects in discrete-impulse energy transformation. *Engineering Physics Journal*, 78(1), 15-22.

Dyakonova, A. K., & Bezusov, A. T. (2006). *Structurants in the production of canned products*. Odessa: "Optimum", 249 p.

Flaumenbaum, B. L., Bezusov, A. T., Storozhuk, V. M., & Khomich, G. P. (2006). *Physico-chemical and biological fundamentals of canning production.* Odessa: Printing.

Gong, Z., Yu, M., Wang, X., & Shi, X. (2018). Functionality of spray-dried strawberry powder: effects of whey protein isolate and maltodextrin. *International Journal of Food Properties,* 21(1), 2229—2238. https://doi.org/10.1080/10942912.2018.1506477.

Kernasyuk, Y. (2022). *Global food security: old problems, new challenges, and effective solutions.* Retrieved from https://www.growhow.in.ua/hlobalna-prodovolcha-bezpeka-stari-problemy-novi-vyklyky-ta-efektyvni-rishennia/

Mujumdar, A. S. (Ed.). (2006). *Handbook of Industrial Drying (3rd ed.).* CRC Press. https://doi.org/10.1201/9781420017618

Sharkova, N. O., Zhukotsky, E. K., Dekusha, G. V., & Kostyanets, L. O. (2017). Investigation of the dynamic viscosity of water suspension of shiitake mushroom fruit body. *Scientific Works of NUFT*, 23(6), 219-224.

Skopenko N., & Tikhonova A. (2013). Rational assortment portfolio in accordance to the food security. *Ukrainian Food Journal*, 2(4), 612-617.

Telezhenko, L. N., & Bezusov, A. T. (2004). *Biologically active substances of fruits and vegetables and their preservation during processing*. Odessa: Optimum.

Turchina, T. Ya., Avdeeva, L. Yu., Makarenko, A. A., & Kozak, M. M. (2024). Investigation of the influence of DPIE processing and biopolymer additives on the characteristics of fruit heterogeneous systems as objects of spray drying. *Thermophysics and Thermal Power Engineering*, 46(1), 18-28.

Janiszewska, E. (2014). Microencapsulated beetroot juice as a potential source of betalain. *Powder Technology*, 264, 190-196.