Malkhazi Mikaberidze, 2024, 12:5
ISSN (Online): 2348-4098
ISSN (Print): 2395-4752

International Journal of Science, Engineering and Technology

An Open Access Journal

Intensification of Production of Dry Flour from Roots and Tubers with High Content of Biologically Active Substances

Malkhazi Mikaberidze
Candidate of technical sciences, professor of the Akaki Tsereteli State University,
Member of the Academy of Ecological Sciences of Georgia, Academician, Georgia, Kutaisi

Abstract- The article is devoted to the intensification of the production of dried food additives using the electrophysical method from root and tuber raw materials with the provision of a machine-hardware system. A new technological scheme for the production of dried food additives with high biological activity has been developed; The optimal regime parameters for heat treatment of crushed root and tuber mixture in the field of infrared rays were determined; the main geometric parameters of a drying machine operating on infrared energy were calculated, the energy balance was determined, the main geometric parameters and design diagrams were clarified. A machine for drying a root and tuber mixture using infrared rays is a simple device; occupies a small production area; does not require additional equipment. The process savings (economic effect) when using the experimental machine will be 16,849 US dollars or 0,39 US dollars per 1 kg of product.

Keywords- drying of root and tuber crop raw materials; infrared rays; drying modes

I. INTRODUCTION

Root tubers are plants in which nutrients are concentrated in tubers or roots. Tubers include Jerusalem artichoke, and root vegetables include beets, carrots, parsnips, etc. These products are widely used for nutrition, they contain large quantities of vitamins, microelements and can be classified as products of high biological activity (Mikberidze M. 2020, Oliveira, Sara M., et al. 2016, Verma, Deepak Kumar, et al. 2020 Sablani, Shyam S. 2006).

In food supplements industry actively uses additives (artificial, natural), thanks to which products are given a specific taste, color, aroma, medicinal and preventive properties. Natural additives deserve attention, the use of which is becoming increasingly relevant against the background of the saturation of food products with chemical additives. Research in this direction is relevant and has great prospects (Huang, Dan et al. 2021, Mikberidze, M. 2015,

Kamiloglu, Senem, et al. 2016, Karam, Marie Céleste, et al. 2016, Levina, N.S., et al. 2015, Mutuli, Gibson P., et al. 2020,_Zhang, Min, et al. 2017, Shishir, Mohammad Rezaul Islam, et al. 2017, Puchkova, T.S. 2019, Onwude, Daniel I., et al. 2022, Onwude, Daniel I., et al. 2021, Pozdnyakova, O.G. 2018).

Goals, Objectives, Materials and Methods

The experiments were carried out according to a pre-compiled program and methodology (on the basis of Akaki Tsereteli State University - Faculty of Agriculture, Georgia, Kutaisi).

The process of drying food additives is carried out with the help of convection dryers, which, along with their positive sides, have a number of disadvantages, so it is important to expand research in this direction, which determined the research topic chosen by us - drying food additives (roots and tubers) in the field of infrared rays (IR) (Barba, et al. 2015, Inyang, et al. 2018, Li, et al. 2023, Mikberidze, M. 2015, Mikberidze M. 2020, Akter, Ferdusee, et al.2022, Ahmed, Naseer, et al. 2013, Bassey, et al. 2021, Boateng, Isaac Duah. 2023, Bala, B. K. et al 2009, Chibuzo, et al. 2021, Changrue, Viboon, et al. 2006, Calín-Sánchez, Ángel, et al. 2020).

The purpose of our study was to determine the optimal regime parameters for heat treatment (drying) of a mixture of crushed root and tuber raw materials (artichoke, beets, carrots, parsnips) in the field of infrared (IR) rays; Development of a new technological scheme for the production of food additives (flour of root and tuber crop raw materials) having high nutritional value with a high content of biologically active substances and specific organoleptic properties; clarification of the basic geometric parameters of an infrared drying experimental machine for drying sugar-containing root and tuber crop raw materials, calculation of the energy balance of the machine, development of design diagrams, determination of economic efficiency (Huang, Dan et al. 2021, Hnin, et al. 2018, Mikberidze M. 2019, Mikberidze M. 2020, Deng, Li-Zhen, et al. 2019, Devahastin, Sakamon, et al. 2010, Jayaraman, K. S., et al. 2020, Figiel, Adam, et al. 2016, Fan, Kai, Min Zhang, et al. 2019, Fan, Kai, Min Zhang, et al. 2017, Hasan, Mahmood Ul, et al. 2019,_Zhang, Min, Hao Jiang, et al. 2010).

IR radiation energy was chosen as the energy source. It is known that infrared rays significantly intensify technological processes, simplify technological equipment, improve working conditions, eliminate environmental pollution, etc. A laboratory drying installation was used for the experiments (Du, Yuanjie et al. 2023, Huang, Dan et al. 2021, Mikberidze M. 2012, Mikaberidze M. 2013, Solchansanj, Sliahab et al. 2020, Zhang, Dongyan et al.2023, Zhang, Wei-Peng, et al. 2022, Zhang, Wei-Peng, et al. 2022, Salehi, Fakhreddin, et al. 2020).

To study the process of heat treatment of root and tuber crop raw materials, a special methodology was developed, the main factors influencing the process and their relationships were identified.
Infrared irradiation measurements using a thermoelectric device (DTP0924ROP50-50JO). The process temperature was measured with a mercury thermometer and an infrared thermometer (RaytekMiniTempMT6). The residual moisture in the material was determined with a moisture meter (ECV-4V). Carbohydrates were determined by analytical method, mineral substances were determined using the dry ashing method., ascorbic acid was determined by the titrimetric method, the total amount of organic acids was determined by the chromatographic method.

Based on the methodology, the following materials were selected for research: Jerusalem artichoke, beets, carrots, parsnips, from which the raw materials were prepared - lightly crushed test material with skin (proportion - in equal quantities).

For the purpose of heat treatment, the raw materials were introduced pre-heated in a laboratory chamber equipped with IR generators (NIK-220-1000) and evenly distributed onto a metal mesh. The temperature in the drying chamber was maintained by selectively switching on the IR generators and by regulating the air flow supplied to the chamber.

The drying process was accepted as complete after monitoring the residual moisture of the material, visual and organoleptic inspection.

When determining the optimal value of one of the parameters operating in the process, all other parameters had constant values (Hii, Ching Lik et al. 2021, Mikaberidze M. 2022, Mikaberidze M. et al. 2021, Zeng, Shiyu et al. 2022, Zhou, Xu, et al. 2019, Mercer, Donald G., et al. 2012, Natarajan, Sendhil Kumar, et al. 2022, Onwude, Daniel I., et al. 2016, Onwude, Daniel I., et al. 2017, Zhang, Min, et al. 2006).

II. SCIENTIFIC NOVELTY

The technological scheme we have chosen for the production of flour from root and tuber crop raw materials using infrared energy has the following form:

Raw materials (artichoke, beets, carrots, raw parsnips) - inspection - washing - sorting - cutting - drying with infrared energy (first stage of drying) - delay (moisture migration) - drying with infrared energy (second stage of drying) - grinding - sorting (fig. 1).

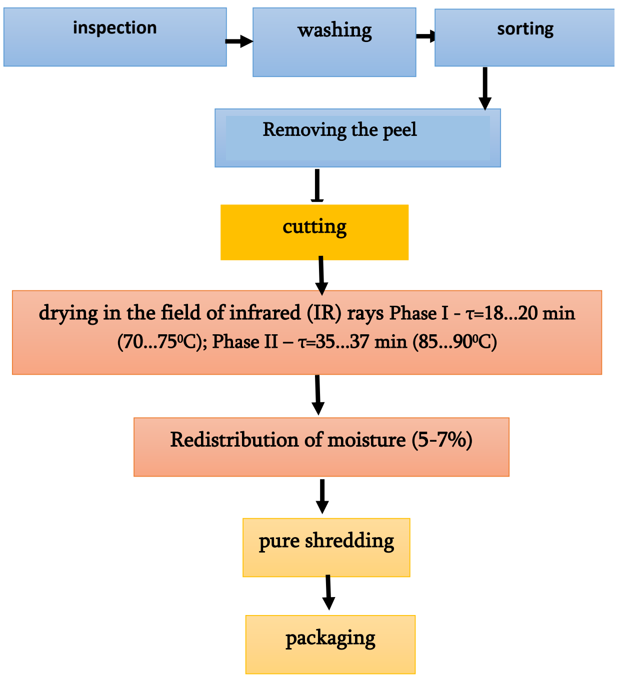

Fig. 1: The technological scheme for the production of flour from root and tuber crop raw materials using infrared energy

Numerous experiments have shown that artificial drying of the material under study is effective in two drying phases (drying phase I - 70...75 ^{0}C, drying phase II - 85...90 ^{0}C).

As a result of the research, drying modes for root and tuber raw materials in the field of IR rays were established, namely: with continuous irradiation: type of generators – NIK-220-1000; type of irradiation - bilateral; Irradiation density P=0.35-0.40 kW/m^2; distance between the material under study and the IR ray generators H=25 cm; Material thickness δ=5 cm; Duration of thermal irradiation - Phase I - τ=18...20 min (70...75^{0}C); Phase II – τ=35...37 min (85...90^{0}C); the final residual moisture content of the semi-finished product is 5-7% (Mikberidze M. 2022, Solchansanj, Sliahab et al. 2020).

The experimental results showed that the specific effective effect of IR rays on the material significantly improves the quality of the semi-finished product (see Table 1).

Table 1: Comparative characteristics of the chemical analysis of the semi-finished product

Drying type	Carbohydrates, g	Organic acids, g	Minerals, g	Ascorbic acid, mg
Drying using current technology	10,5	1,5	0,87	3.5
Drying with IR rays	10,5	1,7	0,87	6.4

In order to provide a machine-hardware system for the process of drying root and tuber crop raw materials with IR rays, based on a generalization of experimental and theoretical data, the main geometric parameters of a drying machine operating on IR energy were calculated, the energy balance was determined, the main geometric parameters were clarified, and design diagrams were created (Reis, Felipe Richter, et al. 2022, Radhakrishnan, Ganesh, et al. 2024, Sagar, V. R., et al. 2010, Tan, Choon Hui, et al. 2022, Wu, Jiaxin, et al. 2022, Xu, Baoguo, et al. 2022, Sehrawat, Rachna, et al. 2019)

At the same time, modern production requirements were taken into account and the machine was designed for productivity G=100 kg/h (fig. 2).

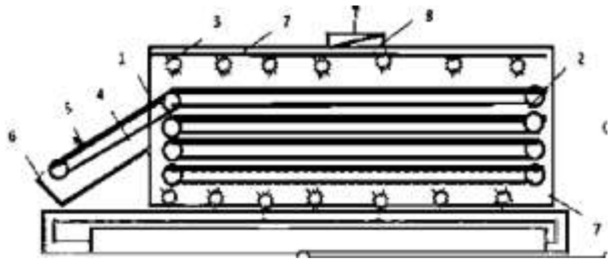

Fig. 2 Scheme of a machine for drying root and tuber crop raw materials using the electrophysical method

Operating principle of the machine: three working mesh conveyors and one external mesh conveyor (2) are installed in a heat-insulated metal drying chamber (1). The material is supplied to the conveyor (2) by an elevator (4) from a hopper (6), on which a layer leveling mechanism (5) is installed. The process of drying the sugar-containing root and tuber mixture is carried out on all conveyors using IR generators (3), moist air is removed by an air exhaust (8). To reduce energy losses, aluminum reflectors (7) are installed on the inner surface of the drying chamber. The dried mass is discharged through a semi-closed opening at the front of the machine. The drying process is adjusted by adjusting the speed of the working conveyor. The inclusion of IR generators in the electrical network has been differentiated.

Total Heat Consumption in the Dryer:

$Q=Q_1+Q_2+Q_3$ kJ/h.

here Q_1 - heat consumption for heating the root and tuber mixture, kJ/h;

Q_2 - heat consumption for moisture evaporation, kJ;

Q_3 - heat loss to the environment, kJ/h.

$Q_1=Gc(t_2-t_1)=100\cdot3{,}45(75-20)=18975$ (5 kW/h)

here G - drying machine productivity, G=100 kg/h;

c – specific heat capacity of the root and tuber mixture, 3,45 kJ/kg°C;

t_1 – initial temperature of the root and tuber mixture, 20^0C;

t_2 – mass temperature at the outlet of the drying machine, 75^0C.

$Q_2=w\cdot r=83\cdot2350=124550$ (54kW/h)

here w – mass of moisture evaporated from the root and tuber mixture, kg/h;

r – latent heat of vaporization of water.

$w=G(w_1-w_2)/(100-w_2)=83$ kg.h

here w_1 – initial moisture content of the root and tuber mixture, w_1=82...84%;

w_2 – final moisture content of the root and tuber mixture, w_2=5...7%.

$Q_3=Q_{camera}+Q_{air}=3{,}6\cdot F(t_{cт}-t0)+L(I_2-I_0)=3{,}6\cdot12{,}54\cdot37(60-20)+200(100-50)=76800$ (21kW/h)

here α - heat transfer coefficient,

$\alpha=9{,}74+0{,}07(tat-t_0)=9{,}74+0{,}07(60-20)=12{,}54$ kW/m^{20}C.

t_0 – ambient temperature, t_0=20...22^{0}C;

tat – average temperature of the outer surface of the drying chamber wall, tat = 50...60^{0}C;

F – outer surface area of the drying chamber, m^2;

L – mass of air entering the chamber in an unorganized form, L=200 kg/h.

I_0 and I_2 – specific enthalpies of air, I_0=50kJ/h, I_2=100kJ/h.

Consequently, the total power of infrared generators is:

- P_{theory}=80 kW /h;
- $P_{reality}=p/\eta=/80/0{,}95=84=$ kW/h

Working surface of the drying conveyor: F=37m^2

$V=G/3600\beta\ t\ \varphi=0{,}005$ m/s

here β - conveyor width, β =1,5 m;

φ- duty factor, φ = 0,9;

Total length of the drying conveyor: $l=V\cdot t=0{,}005\cdot0{,}5\cdot3600=9$ m.

here τ- maximum value of the drying process, τ= 0,5 h.

Height of the dryer H=2,5...3 m

III. DETERMINATION OF THE ECONOMIC EFFICIENCY OF A DRYING MACHINE FOR SUGAR-CONTAINING ROOT AND TUBER CROP RAW MATERIALS

Operating using the electrophysical method

Experimental machine for drying sugar-containing root and tuber crop raw materials

1. Amortization
The device operates all year round 720 hours (30x8x3) here 30 - number of days in a month;
8 - working hours;
3 - The number of working months.

During operation, the experimental machine as a whole will operate for 720x6=4320 hours.
here 6 - the service life of the machine.

In general, during operation, the experimental machine will heat treat 4320x100 = 432,000 kg of raw materials.
Thus, the amortization of the machine is 4500: 432000 = 0,01 US dollars / 100 kg of raw materials.

2. Remuneration of Service Personnel
The experimental machine requires 1 maintenance personnel, whose monthly salary is 400 US dollars. Since the device operates on average 3 months during the year, the costs for maintenance personnel will be equal - 400x3 = 1200 US dollars.

Thus, 1200: 720 = 1,67 US dollars/100 kg of raw materials.

here 720 h - operation of the experimental machine all year round.

3. Cost of Electricity
The experimental machine consumes 30x3x672 = 60480 kW of electricity during the year.

- here 30 - the number of days in a month;
- 672 - electrical energy consumed during the day in kW.
- The cost of electricity during the year is - 60480x0,10 = 6048 US dollars.
- Thus, 6048:720 = 8,40 US dollars/100 kg of raw materials.

4. The Cost of Repairs
The amount that will be spent on repairing the experimental machine during the year is 200 US dollars.

Thus, 200:720 = 0,28 US dollars/kg of raw materials.

Thus, when using an experimental machine, taking into account the process of heat treatment of raw materials, the cost of production increases by 0,01 + 1,67 + 8,40 + 0,28 = 10,36 US dollars per 100 kg of raw materials, or 0,104 US dollars per 1 kg.

The cost of the experimental installation for heat treatment of raw materials - the cost is equal to: 432000x0,104 = 44927 US dollars.

Operating Convection Drying Machine
Amortization - 10,000:432,000 = 0,023 US dollar/100 kg of raw materials.

- 2400:720 = 3,33 US dollars (maintenance of 2 staff units);
- The electricity consumed by the operating machine during the year is 75,600 kW, which is equal to the cost of 7,560 US dollars per year.
- Thus, 7560:720 = 10,5 US dollar / 100 kg of raw materials.

The amount that will be spent on repairing the operating machine during the year is 300 US dollars.

Thus, 300:720 = 0,42 US dollar / 100 kg of raw materials.

Thus, when using an existing convection machine, taking into account the process of heat treatment of raw materials, the cost of products increases by 0,023 + 3,33 + 10,5 + 0,42 = 14,27 US dollars per 100 kg of raw materials, or 0,143 US dollars per 1 kilogram.

Costs for an operating convective machine for heat treatment of raw materials - the cost is equal to: 432000x0,143 = 61776 US dollars.

Thus, the process savings (economic effect) when using the experimental machine will be 61776-44927 = 16849 US dollars or 0,39 US dollars per 1 kg of product.

IV. CONCLUSION, RESULTS, CONCLUSIONS

factors and the interrelationship between the processes of thermal processing of root and tuber raw materials in the field of IR rays are revealed: the density of irradiation, the distance between the raw material and the IR generators, the thickness of the layer, the duration of the process, the humidity of the material before and after drying, the type of irradiation (double, single, continuous), temperature process.

In the result of the research, the drying regimes of root and tuber raw materials are established in the field of IR rays, namely: under continuous irradiation: generator type - NIK-220-1000; type of irradiation - double-sided; Irradiation density P=0,35-0,40 kW/m^2; the distance between the research material and the generators of IR rays H=25 cm; Thickness of the material δ=5 cm; Duration of thermal irradiation - I phase - τ=18...20 min (70...75^{0}C); Phase II – τ=35...37 min (80...85^{0}C); residual moisture semi-fabricated 5-7%.

The main geometrical parameters of the machine for drying root and tuber raw materials, working on infrared energy, were calculated, the energy balance was determined, and construction schemes were compiled.

The technological method of thermal processing (drying) of crushed root and tuber mixture in the field of infrared rays is expedient and promising. The intensity of the process increases 5 times and more compared to the existing drying methods, which positively affects the biologically active substances and the quality of the product; the technological process and technological equipment are simplified, eliminating the procession of the environment; It allows to fully automate the process and so on.

The process of drying the mixture of roots and tubers increases the concentration of nutrients of the semi-finished product several times compared to the original raw material. Flour from root crops has a high food value and can be used in confectionery additives to give products a specific taste, color, aroma, therapeutic and preventive properties.

A machine for drying root and tuber mixtures with infrared rays is a simple device; very small production area; does not require additional equipment.

The saving of the process (economic effect) when using the experimental one gives 16,849 US dollars or 0,39 US dollars per 1 kg of product.

Contribution

The author carried out the research, data analysis, preparation of the manuscript material and is responsible for any potential plagiarism.

Huge thanks to the administration of the Akaki Tsereteli State University for support and financial support.

REFERENCES

1. Akter, Ferdusee, et al. (2022). "A comprehensive review of mathematical modeling for drying processes of fruits and vegetables." International Journal of Food Science 2022.1. 6195257. https://doi.org/10.1155/2022/6195257;
2. Ahmed, Naseer, et al. (2013). "Different drying methods: their applications and recent advances." International Journal of food nutrition and safety 4.1. 34-42. https://www.researchgate.net/profile/Dr-Naseer-Ahmed/publication/275650176_Different_Drying_Methods_Their_Applications_and_Recent_Advances/links/554260770cf23ff716835b85/Different-Drying-Methods-Their-Applications-and-Recent-Advances.pdf;
3. Barba, Francisco H., Alexey Parnyakov, Sofia A. Pereira, Arthur Victor, Nabil Grimi, Nadia Bussetta, Jorge A. Saraiva, et al. (2015). "Current applications and new opportunities for the use of pulsed electric fields in food science and industry." Food Research International 77, 773-798. https://doi.org/10.1016/j.foodres.2015.09.015;
4. Bassey, Edidiong Joseph, Jun-Hu Cheng, and Da-Wen Sun. (2021). "Novel nonthermal and thermal pretreatments for enhancing drying performance and improving quality of fruits and vegetables." Trends in Food Science & Technology 112. 137-148. https://doi.org/10.1016/j.tifs.2021.03.045;
5. Boateng, Isaac Duah. (2023). "Thermal and nonthermal assisted drying of fruits and vegetables. Underlying principles and role in physicochemical properties and product quality." Food Engineering Reviews 15.1. 113-155. https://link.springer.com/article/10.1007/s12393-022-09326-y;
6. Bala, B. K., and Serm Janjai. (2009). "Solar drying of fruits, vegetables, spices, medicinal plants and fish:

Developments and Potentials." International solar food processing conference. http://images3.wikia.nocookie.net/solarcooking/images/e/ef/Solar_drying_of_fruits,_vegetables,_spices,_medicinal_plants_and_fish-_Developments_and_Potentials_-_B.K._Bala_and_Serm_Janjai_2009.pdf;

7. Chibuzo, Nwankwo S., et al. (2021)."Technological advancements in the drying of fruits and vegetables: A review." African Journal of Food Science 15.12. 367-379. https://doi.org/10.5897/AJFS2021.2113;
8. Changrue, Viboon, et al. (2006)."Microwave drying of fruits and vegetables." Stewart Postharvest Review 2.6. 1-7. https://www.researchgate.net/publication/233657717;
9. Calín-Sánchez, Ángel, et al. (2020)."Comparison of traditional and novel drying techniques and its effect on quality of fruits, vegetables and aromatic herbs." Foods 9.9. 1261. https://doi.org/10.3390/foods9091261;
10. Du, Yuanjie et al. (2023). Drying kinetics of paddy rice using graphene far-infrared drying equipment under different IR temperatures, irradiation distances, grain flow and drying rates. Case Studies in Thermal Engineering 43. DOI: 10.1016/j.csite.2023.102780;
11. Deng, Li-Zhen, et al. (2019)."Chemical and physical pretreatments of fruits and vegetables: Effects on drying characteristics and quality attributes–a comprehensive review." Critical reviews in food science and nutrition 59.9. 1408-1432. https://doi.org/10.1080/10408398.2017.1409192;
12. Devahastin, Sakamon, and Chalida Niamnuy. (2010). "Invited review: modelling quality changes of fruits and vegetables during drying: a review." International Journal of Food Science & Technology 45.9. 1755-1767 https://doi.org/10.1111/j.1365-2621.2010.02352. Ertekin, Can, et al. (2023). "Drying of fruits and vegetables." Drying technology in food processing. Woodhead Publishing, 491-542. https://doi.org/10.1016/B978-0-12-819895-7.00004-3;
13. Inyang, Uwem Ekwere, Innocent Oseribho Obo and Benjamin Reuben Etuk. (2018). "Kinetic models of drying methods for food materials." Advances in Chemical Technology and Science 8, no. 2. 27–48. https://doi.org/ 10.4236/aes.2018.82003;
14. Jayaraman, K. S., and DK Das Gupta. (2020). "Drying of fruits and vegetables." Handbook of industrial drying. CRC Press. 643-690. https://www.taylorfrancis.com/chapters/edit/10.1201/9780429289774-21/drying-fruits-vegetables-jayaraman-das-gupta;
15. Figiel, Adam, and Anna Michalska. (2016). "Overall quality of fruits and vegetables products affected by the drying processes with the assistance of vacuum-microwaves." International Journal of Molecular Sciences 18. 71. https://doi.org/10.3390/ijms18010071;
16. Fan, Kai, Min Zhang, and Arun S. Mujumdar. (2019)."Recent developments in high efficient freeze-drying of fruits and vegetables assisted by microwave: A review." Critical reviews in food science and nutrition 59.8 .1357-1366. https://doi.org/10.1080/10408398.2017.1420624;
17. Fan, Kai, Min Zhang, and Arun S. Mujumdar. (2017). "Application of airborne ultrasound in the convective drying of fruits and vegetables: A review." Ultrasonics Sonochemistry 39. 47-57. https://doi.org/10.1016/j.ultsonch.2017.04.001;
18. Huang, Dan and others. (2021). Application of infrared radiation for drying food products. Trends in Food Science and Technology. DOI: 10.1016/j.tifs.2021.02.039; Hasan, Mahmood Ul, et al. (2019)."Modern drying techniques in fruits and vegetables to overcome postharvest losses: A review." Journal of Food Processing and Preservation 43.12. e14280. https://doi.org/10.1111/jfpp.14280;
19. Hii, Ching Lik, Sze Pheng Ong, Jing Ying Yap, Aditya Putranto, and Dave Mangindaan. (2021). "Hybrid drying of food and bioproducts: A review." Drying Technology 39, no. 11. 1554-1576. https://doi.org/10.1080/07373937.2021.1914078;
20. Hnin, Kai Haing, Min Zhang, Arun S. Mujumdar, and Yueling Zhu. (2018). "New food drying technologies with energy-saving characteristics: a review." Drying technology https://doi.org/10.1080/07373937.2018.1510417;
21. Kumar, Chandan and M.A. Karim. (2019). "Microwave convective drying of food materials: a critical review." Critical Reviews in Food Science and Nutrition 59, no. 3. 379–394. https://doi.org/10.1080/10408398.2017.1373269;
22. Kamiloglu, Senem, et al. (2016). "A review on the effect of drying on antioxidant potential of fruits and vegetables." Critical reviews in food science and nutrition 56.sup1. S110-S129. https://doi.org/10.1080/10408398.2015.1045969
23. Karam, Marie Céleste, et al. (2016)."Effects of drying and grinding in production of fruit and vegetable powders: A review." Journal of Food Engineering 188. 32-49. https://doi.org/10.1016/j.jfoodeng.2016.05.001;
24. Li, Caiyun, et al. (2023). Effects of Different Drying Methods on the Drying Characteristics and Drying Quality of Cistanche Deserticola.;

25. Levina, N.S., Kondratova T.A., Bidey I.A. (2015). Study of the drying process of Jerusalem artichoke tubers under different feeding methods. Agricultural Machinery and Technologies 2. 16-19. https://www.vimsmit.com/jour/article/view/60?locale=en_US;
26. Mikberidze, M. (2015). Processes and machine-equipment systems of food production. (Textbook). Georgia, Kutaisi: Akaki Tsereteli State University. 492 . https://orcid.org/0009-0009-5337-4691;
27. Mikberidze M. (2019). Basic methods of processing raw materials in the process of producing food products. (Textbook). Georgia, Kutaisi: LLC "MBM Polygraph", Akaki Tsereteli State University. 290. https://orcid.org/0009-0009-5337-4691;
28. Mikberidze M. (2020). Fundamentals of planning food enterprises for processing agricultural raw materials. (Textbook). Georgia, Kutaisi: LLC "MBM Polygraph", Akaki Tsereteli State University. 272. https://orcid.org/0009-0009-5337-4691;
29. Mikberidze M. (2012). Calculation and selection of some machine-hardware systems in the food industry. (Reference book). Georgia, Kutaisi: Akaki Tsereteli State University. 100. https://orcid.org/0009-0009-5337-4691;
30. Mikberidze M. (2022). Calculation of a drying machine for tomato raw materials operating on the energy of infrared rays. In: "GLOBAL SCIENCE AND INNOVATIONS 2022: CENTRAL ASIA" SERIES "AGRICULTURAL SCIENCES" Nur-Sultan (Astana), Kazakhstan. 41-46. http://bobek-kz.com;
31. Mikaberidze M. (2013). Calculation of machines and devices in the food industry. (Directory). Georgia, Kutaisi: Akaki Tsereteli State University. 80 . https://orcid.org/0009-0009-5337-4691;
32. Mikaberidze M. (2022). Improving the production of confectionery additives by the electrophysical method from a mixture of sugar-containing root and tuber raw materials. In: "GLOBAL SCIENCE AND INNOVATIONS 2022: CENTRAL ASIA" SERIES "AGRICULTURAL SCIENCES" Nur-Sultan (Astana), Kazakhstan. 36-39. http://bobek-kz.com;
33. Mikaberidze M. et al. (2021). Improving the production of confectionery additives using the electrophysical method from a mixture of wild fruit and berry raw materials. In: SYSTEM ANALYSIS AND SYNTHESIS OF MODELS OF SCIENTIFIC DEVELOPMENT OF SOCIETY. Collection of articles based on the results of the International Scientific and Practical Conference. Russia, Moskva. 98-101. https://ami.im/sbornik/MNPK-358.pdf;
34. Mikaberidze M. (2016). Regime parameters for storage and processing of fruits and vegetables. (Textbook). Georgia, Kutaisi: Akaki Tsereteli State University. 188. https://orcid.org/0009-0009-5337-4691;
35. Mutuli, Gibson P., Ayub N. Gitau, and Duncan O. Mbuge. (2020). "Convective drying modeling approaches: a review for herbs, vegetables, and fruits." Journal of Biosystems Engineering 4. 197-212. https://link.springer.com/article/10.1007/s42853-020-00056-9 ;
36. Mercer, Donald G., and P. Eng. (2012)."A Basic Guide to Drying Fruits and Vegetables." University of Guelph: Guelph, ON, Canada. https://iufost.org/iufostftp/Guide%20to%20Drying-Part1.pdf;
37. Natarajan, Sendhil Kumar, et al. (2022). "Review on solar dryers for drying fish, fruits, and vegetables." Environmental Science and Pollution Research 29.27. 40478-40506. https://link.springer.com/article/10.1007/s11356-022-19714-w;
38. Onwude, Daniel I., et al. (2016). "Modeling the thin-layer drying of fruits and vegetables: A review." Comprehensive reviews in food science and food safety 15.3. 599-618. https://doi.org/10.1111/1541-4337.12196;
39. Onwude, Daniel I., et al. (2017). "Non-thermal hybrid drying of fruits and vegetables: A review of current technologies." Innovative Food Science & Emerging Technologies 4. 223-238. https://doi.org/10.1016/j.ifset.2017.08.010
40. Onwude, Daniel I., et al. (2022). "How much do process parameters affect the residual quality attributes of dried fruits and vegetables for convective drying?."Food and Bioproducts Processing 131. 176-190. https://doi.org/10.1016/j.fbp.2021.11.005;
41. Onwude, Daniel I., et al. (2021). "Electrohydrodynamic drying: Can we scale-up the technology to make dried fruits and vegetables more nutritious and appealing?."Comprehensive Reviews in Food Science and Food Safety 20.5 5283-5313. https://doi.org/10.1111/1541-4337.12799;
42. Oliveira, Sara M., Teresa RS Brandao, and Cristina LM Silva. (2016). "Influence of drying processes and pretreatments on nutritional and bioactive characteristics of dried vegetables: A review." Food Engineering Reviews 8.2. 134-163. https://link.springer.com/article/10.1007/s12393-015-9124-0;
43. Puchkova, T.S. (2019). About the universal technology of processing jerusalem artichoke and chicory for inulin / T.S. Puchkova, D.M. Pikhalo, O.M. Karasyova // Food systems. V.2. № 2. 36–43. https://doi.org/10.21323/2618–9771–2019–2–2–36–43;

44. Pozdnyakova, O.G. (2018). Development of technology for the production of functional confectionery products / O.G. Pozdnyakova, E.A. Egushova, E.A. Tyshchenko // Equipment and technology of food production. Vol. 48, No. 3. 90–95. https://doi.org/10.21603/2074–9414–2018–3–90–95;
45. Reis, Felipe Richter, et al. (2022). "Trends in quality assessment and drying methods used for fruits and vegetables." Food Control 142. 109254. https://doi.org/10.1016/j.foodcont.2022.109254;
46. Rodríguez, Óscar, et al. (2018)."Application of power ultrasound on the convective drying of fruits and vegetables: effects on quality." Journal of the Science of Food and Agriculture 98.5.1660-1673. https://doi.org/10.1002/jsfa.8673;
47. Radhakrishnan, Ganesh, et al. (2024). "A Comparative Management Analysis on the Performance of Different Solar Drying Methods for Drying Vegetables and Fruits." Sustainability 16.2. 775. https://doi.org/10.3390/su16020775;
48. Solchansanj, Sliahab and Digvir S. Jayas. (2020). "Drying of food products." In Handbook of Industrial Drying. 589-625. CRC Press, https://www.taylorfrancis.com/chapters/edit/10.1201/9780429289774-19/dryingfoodstuffssliahab-solchansanj-digvirjayas;
49. Sablani, Shyam S. (2006). "Drying of fruits and vegetables: retention of nutritional/functional quality." Drying technology 24.2.123-135. https://doi.org/10.1080/07373930600558904;
50. Sagar, V. R., and P. Suresh Kumar. (2010). "Recent advances in drying and dehydration of fruits and vegetables: a review." Journal of food science and technology 47. 15-26. https://link.springer.com/article/10.1007/s13197-010-0010-8;
51. Shishir, Mohammad Rezaul Islam, and Wei Chen. (2017). "Trends of spray drying: A critical review on drying of fruit and vegetable juices." Trends in food science & technology 65. 49-67. https://doi.org/10.1016/j.tifs.2017.05.006;
52. Sehrawat, Rachna, et al. (2019). "Drying of fruits and vegetables in a developed multimode drying unit and comparison with commercially available systems." Journal of The Institution of Engineers (India): Series A 100. 381-386. https://link.springer.com/article/10.1007/s40030-019-00371-1;
53. Salehi, Fakhreddin, and Sara Aghajanzadeh. (2020). "Effect of dried fruits and vegetables powder on cakes quality: A review." Trends in Food Science & Technology 95. 162-172. https://doi.org/10.1016/j.tifs.2019.11.011;
54. Shende, Deepika, and Ashis K. Datta. (2019). "Refractance window drying of fruits and vegetables: A review." Journal of the Science of Food and Agriculture 99.4. 1449-1456. https://doi.org/10.1002/jsfa.9356;
55. Tan, Choon Hui, et al. (2022). "Valorization of fruits, vegetables, and their by-products: Drying and bio-drying." Drying Technology 40.8.1514-1538. https://doi.org/10.1080/07373937.2022.2068570;
56. Verma, Deepak Kumar, et al. (2020). "Effects of drying technology on physiochemical and nutritional quality of fruits and vegetables." Emerging thermal and nonthermal technologies in food processing. Apple Academic Press, 69-116. https://www.taylorfrancis.com/chapters/edit/10.1201/9780429297335-3/effects-drying-technology-physiochemical-nutritional-quality-fruits-vegetables-deepak-kumar-verma-mamta-thakur-prem-prakash-srivastav-vahid-mohammadpour-karizaki-hafiz-ansar-rasul-suleria;
57. Wu, Jiaxin, Liang Zhang, and Kai Fan. (2022). "Recent advances in ultrasound-coupled drying for improving the quality of fruits and vegetables: a review." International Journal of Food Science & Technology 57.9. 5722-5731. https://doi.org/10.1111/ijfs.15935;
58. Xu, Baoguo, et al. (2022)."Recent development in high quality drying of fruits and vegetables assisted by ultrasound: A review." Food Research International 152. 110744. https://doi.org/10.1016/j.foodres.2021.110744;
59. Zeng, Shiyu et al. (2022). Innovative applications, limitations and prospects of energy-bearing infrared, microwave and radio frequency radiation in agricultural processing. Trends in Food Science and Technology. DOI: 10.1016/j.tifs.2022.01.032;
60. Zhang, Dongyan et al.. (2023). Far-infrared drying characteristics and energy consumption of ginger slices using ultrasonics." Ultrasound Sonochemistry. DOI: 10.1016/j.ultsonch.2022.106287;
61. Zhang, Min, Bhesh Bhandari, and Zhongxiang Fang. (2017). Handbook of drying of vegetables and vegetable products. CRC Press, https://www.taylorfrancis.com/books/mono/10.4324/9781315152677/handbook-drying-vegetables-vegetable-products-min-zhang-bhesh-bhandari-zhongxiang-fang;
62. Zhou, Xu, and Shaojin Wang. (2019). "Recent Developments in Radiofrequency Drying of Food and Agricultural Products: A Review." Drying Technology 37, no. 3. 271–286. https://doi.org/10.1080/07373937.2018.1452255;
63. Zhang, Min, et al. (2006). "Trends in microwave-related drying of fruits and vegetables." Trends in

Food Science & Technology 17.10. 524-534. https://doi.org/10.1016/j.tifs.2006.04.01;

64. Zhang, Min, Hao Jiang, and Rui-Xin Lim. (2010)."Recent developments in microwave-assisted drying of vegetables, fruits, and aquatic products—drying kinetics and quality considerations." Drying Technology 28.11. 1307-1316. https://doi.org/10.1080/07373937.2010.524591;
65. Zhang, Wei-Peng, et al. (2022). "The influence mechanism and control strategy of relative humidity on hot air drying of fruits and vegetables: A review." Drying Technology 40.11. 2217-2234. https://doi.org/10.1080/07373937.2021.1943669;
66. Zhang, Wei-Peng, et al. (2022). "The influence mechanism and control strategy of relative humidity on hot air drying of fruits and vegetables: A review." Drying Technology 40.11. 2217-2234. https://doi.org/10.1080/07373937.2021.1943669.