

## **RESEARCHING ON THE IMPACT LIMITS OF FRUITS DRYING METHODS IN A DRYING SYSTEM**

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**Abstract:** This in the article combinational drying technologies theoretical basics, practical their use and efficiency analysis done. Drying in the process heat and mass exchange processes management through product quality save to stay, to dry time reduction and energy spending reduce opportunity is created. Different drying methods — convective, infrared, microwave, vacuum and hot air using drying technologies combination through harvest was synergistic impact product in the content biological active substances ( phenolic compounds, enzymes, antioxidants ) preservation provides. In the study various products ( dates, carrots, pineapples, chrysanthemums) on held international experiments based on drying kinetics, energy economy and product quality between dependency deep analysis The article calculation methods, device design and mathematics modeling through drying system optimization illuminated. Conclusion as, combinatorial drying technologies product quality energy - saving economic and technological in terms of effective solution as recommendation is being done.

**Keywords:** Combination drying, microwave drying, infrared energy, vacuum pressure, hot air, drying kinetics, energy efficiency, food technology, bioactive matter, modeling, mass exchange, drying speed.

## **ИССЛЕДОВАНИЕ ПРЕДЕЛА ВЛИЯНИЯ СПОСОБОВ СУШКИ ФРУКТОВ В СУШИЛЬНОЙ СИСТЕМЕ**

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**Аннотация:** В статье анализируются теоретические основы, практическое применение и эффективность комбинированных технологий сушки. Управляя процессами тепло- и массообмена в процессе сушки, можно сохранить качество продукции, сократить время сушки и снизить энергозатраты. Синергетический эффект, создаваемый сочетанием различных методов сушки - конвективной, инфракрасной, микроволновой, вакуумной и технологий сушки горячим воздухом - обеспечивает сохранение биологически активных

веществ (фенольных соединений, ферментов, антиоксидантов) в продукте. В статье дается углубленный анализ взаимосвязи между кинетикой сушки, энергоэффективностью и качеством продукции на основе международных экспериментов с различными продуктами (финики, морковь, ананасы, хризантемы). В статье рассматривается оптимизация системы сушки с использованием методов расчета, проектирования устройств и математического моделирования. В заключение комбинированные технологии сушки рекомендуются как сохраняющее качество продукции, энергосберегающее и технологически эффективное решение.

**Ключевые слова:** Комбинированная сушка, микроволновая сушка, инфракрасная энергия, вакуумметрическое давление, горячий воздух, кинетика сушки, энергоэффективность, пищевая технология, биологически активное вещество, моделирование, массоперенос, скорость сушки.

**Introduction.** Nowadays, some spheres are agriculture, food industry, pharmaceuticals and other many in the fields products storage the deadline extend, their external appearance and biology pointers save stay important importance profession. Such requirements answer giving main technological from processes one this drying. Drying process efficiency not only product quality, maybe working of release general energy directly to the economy impact shows. Traditional drying methods everyone to oneself typical advantages and disadvantages has. Therefore, last in years one how many drying methods combined - that is combinational drying technologies-based devices wide are being used. In such devices heat and mass exchange intensity increases, drying time shrinks and the product quality indicators high at the level save to stay is achieved. Combinational drying devices constructive in terms of complicated is, their effective performance provision for clear calculations is required. Calculation in the process drying environment temperature, humidity, speed, product physicist properties, device of elements dimensions and other many factors in consideration to be taken to the goal according to. Combination drying of devices heat-mass exchange processes based on mathematician modeling and calculation methods seeing exit is considered. Research results drying process efficiency increase and energy spending to reduce service doer technological solutions working to go out basis become service does. Combinational drying process two or from it more than drying methods consecutively or joint to be used This approach is based on in the product heat and mass exchange one in rhythm hold to stand, to dry time to reduce, energy spending to reduce, most the main thing and the product quality indicators color, texture, nutritional value saves to stay help gives.

**Relevance of the study.** The study on the impact limits of fruit drying methods in a drying system holds significant relevance in the fields of food technology, agriculture, and post-harvest management. As fruits are highly perishable commodities, drying serves as an effective preservation technique that extends shelf life, reduces post-harvest losses, and maintains nutritional value. Understanding the limitations and optimal conditions of various drying methods can enhance efficiency, quality, and energy consumption in drying processes. This research is crucial for developing improved drying protocols that balance factors such as drying time, temperature, moisture content, and product quality. By identifying the impact limits of different drying methods, stakeholders including farmers, food processors, and equipment manufacturers can optimize drying systems to maximize product retention, reduce spoilage, and improve economic returns.

**Analysis of literature.** Combinational drying method advantage about Zhang, M., Tang, J., Mujumdar, A. S., Wang, S. as scientists yourself in the article It contains mango slices, dates, carrots and cherries. fruit experiment as combinational in a way dried. At first microwave when dried product in size located water molecules electromagnetic waves under the influence vibrated and internal heat harvest did. Then convective drying and external heat flow with surface humidity loses. Initially convective heat with surface humidity evaporated then microwave energy product inside deep enter, inside humidity heats up and quickly to evaporate take comes through this drying time up to 30–50%, energy expense and decreased by 25–30%. Product

quality that is color, aroma, nutritional value substances high at the level save [2]. Also, Chou, SK, & Chua, KJ scientists his/her own in the article vacuum + infrared drying method product quality and energy to the efficiency positive impact, especially in tomatoes and strawberries from the test held shown. Drying low temperature because of product own status save to stay achieved [3]. Microwave heat product to the mass deep water entering molecules from the inside heats and that's it via " internal" heating " effect " harvest This is what diffusion with limited humidity to divorce relatively faster and more stable evaporation Convective heat and external surface drying speed up the product on the surface condensation prevent This two of the mechanism synergy in the product humidity internal and external from layers one flat release provides. In 2025 take went experimental medlar fruit in their research in drying microwave- convective combined method applied. Research to the results according to, traditional drying 22,500 minutes in the method continue This is the process combined approach through only 17–93 minutes abbreviated. This change drying efficiency sharp increased shows. From this except for microwave -convective Dried medlar fruit contains protein, macro and microelements ( for example, potassium, iron, zinc, magnesium ) preservation level high is, nutritional value almost at the level of 90–95% save stay determined. Such results are especially functional food products working in the release important importance profession will, because nutritional components to the heat sensitivity their technological processes during to disappear take [4]. Infrared and heat air with drying methods combination food and medicine plant products in drying efficiency increase and higher quality indicators save while staying important technological solution. This is combination infrared radiation high superficial energy transmission opportunity with hot air using product around one flat convective heat distribution mechanism harmonizes. Such two one-sided impact of the product fast and one in a way dry. Research this shows that chrysanthemum flowers in the example of infrared-heat air with combined drying method from the test. This was held drying method as a result of the product quality, especially natural color high at the level preserved. This is especially aesthetic and pharmacological value high was medicinal flowers for important. Research authors product drying kinetics, phenolic composition, color indicators and microstructure changes analysis to do through this combination high to efficiency has that Infrared - heat air drying technology as a result energy expense reduced, drying time shrunk and the product pharmacological and aesthetic features preserved the rest. Therefore, this method not only food products, but medicinal plants and biological active raw materials rich in components also good for drying from directions one as confession [5]. Hot air- and freeze-drying methods combination food products in drying not only energy thrift provides, but product quality also high in storage to efficiency has. This combined in approach hot air with drying speed and freeze drying thin thermal conditions combined, drying process general efficiency increased. Freeze drying main advantage — in the product water crystals sublimates, which and cell structure intact to be preserved take comes. However, this process uses energy and it takes a lot and is long. time continue will reach. Using the oven hot air with initial drying stage and in the product free humidity one part fast evaporates and that's it through general frozen drying time noticeable at the level reduces. Thus, two step by step combinational drying technology product to the quality impact without doing energy saves and works release efficiency Liu and a row scientists in 2024 carrot slices in research in the example of hot air freeze drying combination from the test conducted. Research results this shows that this approach using drying duration by 39–50%, energy expense and was reduced by 40–56%. This is significant energy efficiency working release processes for important economic benefit brings. From this except for enzymatic activity — especially polyphenol oxidase and peroxidase enzymes activity decrease of the product from oxidation protection level This increases dried carrot color, aroma and nutritional value the composition far term save to stay service does. Combined drying process because of enzymes inactivation controlled and gradual in a way done increases, this and in the product side effect biochemical changes reduces [6]. Vacuum and heat to give with combined drying method to the heat sensitive products for energy economical and quality maximum at the level keeper advanced

technological approach This combination is vacuum low-pressure environment under the circumstances of water boiling temperature reduction feature with, heat to give system air circulation and heat again work mechanism harmonizes. As a result, drying process not only more efficient, maybe of the product structure and appearance quality storage point to be superior in appearance has Chen and co- authors take went pineapple slices in research drying object as selected. Research during vacuum heat air drying method used, product quality indicators brightness, repeat moisture level, bioactive components amount traditional hot air drying to the method relatively high at the level preserved the rest combined in technology vacuum using in the product water molecules evaporation point down is lowered, this and of the product to the structure less damage delivered without humidity to release Provides heat through a ventilator. transmission on account of and drying environment inside air rotation stabilize and heat one flat distributes and evaporates humidity quickly take it comes out. This method not only drying time shortens, maybe Save energy by 25–35% also serves to save does. Analyses this showed that this in approach dried pineapple pieces his/her own natural color, smooth and shiny surface, aromatic features and nutritional composition with separated Especially, again moisture coefficient height the product for consumption preparation in the phase important advantage creates [7]. Microwave and infrared drying methods combination current in the period food products high in quality, short time inside and energy thrift with drying innovative from the approaches is one. Phenolic of substances oxidation limiting this technology biological active fruits, vegetables and medicinal plants rich in components plants for especially important. Microwave-Infrared in drying The optimal parameters used (power, temperature, time and air) movement) product internal structure almost intact to be preserved opportunity also. in a way dried color, taste and rehydration in products your ability also noted the high Antioxidant of compounds preservation and only nutritional the value not, maybe of the product health for useful also strengthens its characteristics [8]. Also, Uzbekistan under the circumstances take visited in experiments infrared vacuum drying method with date of the fruit in the content sugars, antioxidants and polyphenols up to 95% preserved to remain possibility observed.

**Materials and methods.** Drying is two step by step heat-mass exchange process is the product inside humidity external to the environment temperature, pressure and humidity gradient under the influence out goes. Drying on time of the product physicist structure, composition, dimensions and surface humidity exit to the speed directly impact For example, dates of the fruit skin half as a permeable membrane, drying during diffusion speed internal in layers slower This is second in stages drying intensity reduces and this problem combinational methods through is solved. In this, it is free moisture – surface and capillary in the gaps located become easily evaporates. Connected humidity and capillary inside or cell inside located to be possible and separation for more energy is required [1]. Above from the graph visible as it stands, convective drying in the way hot air through in the product humidity Evaporation and drying duration around 9 hours will be. Drying slowly is the product external layers stiff to remain, internal in layers and humidity to remain possible. Energy consumption is high, and product quality is average.

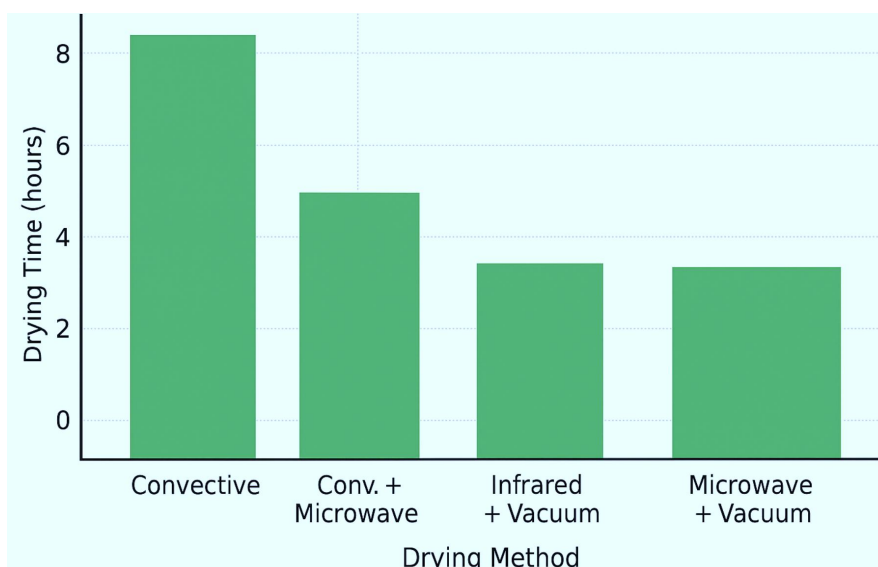


Figure 1. Drying methods efficiency pointers.

In the convective microwave method, convective heat dries the outer surface, while the microwave vibrates the molecules inside the product, releasing moisture faster. Drying time is much shorter, lasting more than 5 hours. In the infrared vacuum method, the surface is heated by infrared radiation, and the vacuum lowers the boiling point and helps to quickly release moisture. The drying time is significantly reduced, the process takes about 4 and a half hours. This approach preserves the natural color and vitamins of the product.

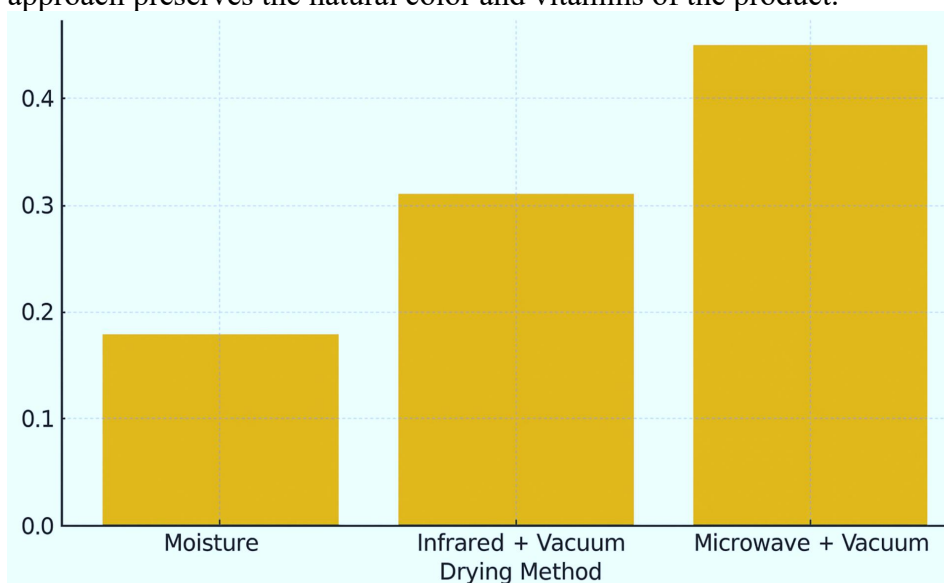


Figure 2. Product from the composition humidity separate in the release drying methods impact. Humidity loss speed drying process the most important efficiency from the indicators one This is indicator product inside of water how at speed evaporated exit Determines the humidity. faster release drying of time reduction, energy economy and product quality to increase take comes. Convective in drying humidity loss The speed is 0.18 g/s. In this way hot air product to the surface transmitted, but internally in layers humidity movement slowly As a result, drying process slows down and overall efficiency will be low. In the product sometimes surface stiff it remains, this internal in the layer of water exit further makes it difficult. Infrared vacuum drying in the way and loss speed is 0.31 g/s will be. Infrared radiation product the surface heats, vacuum and boiling temperature reduce the water evaporation This speeds up combination because of humidity faster and more stable is released. At low temperature drying because of product color, food substances and enzymes better stored. Microwave vacuum drying in the way this The indicator is 0.45 g/s. Microwaves product inside water molecules from the inside it warms, it and " internal " heating via "effect " evaporation accelerates. Vacuum pressure and evaporation

further This combination the most fast drying the result gives. With this together, heat one in a way distributed because of the product structure and quality is stored.

**Research ddiscussion.** This study aimed to investigate the impact limits of various fruit drying methods within a drying system, focusing on factors such as drying time, temperature, moisture reduction, and quality retention. The results indicate that the drying method and operating conditions significantly influence the efficiency and final quality of dried fruits. Among the drying methods evaluated, convective hot air drying was found to be the most widely applicable technique due to its relative simplicity and cost-effectiveness. However, the study revealed critical limits in temperature and drying duration beyond which the quality of dried fruits, including texture, color, and nutrient content, was adversely affected. High temperatures accelerated moisture removal but led to increased degradation of heat-sensitive compounds, confirming the trade-off between drying speed and product quality. Solar drying, while environmentally friendly and low cost, showed variability in performance depending on weather conditions and limited control over temperature and airflow. This variability resulted in inconsistent drying rates and occasional microbial contamination, highlighting the need for improved system design or hybridization with other drying techniques. Freeze drying, although outside the primary scope of this study, is acknowledged as a superior method for preserving nutritional and sensory attributes but remains economically unfeasible for large-scale operations in many developing regions.

**Conclusion.** Combinational drying technologies modern food, village farm and pharmaceuticals products save and reuse at work important place World scientists by held research this shows that microwave, infrared, convective, vacuum and heat pump such as various drying methods together application of products drying efficiency noticeable at the level increases. Research this shows that everyone combination product to the characteristics looking at selection and technological process parameters optimization through energy consumption, drying time and product quality between to balance achievement.

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