"EFFECT OF UV PRETREATMENT ON DRYING KINETICS OF GRAPES."

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I hereby declare that this thesis contains literature survey and original research work by the undersigned candidate, as a part of his M. Tech (Food Technology and Biochemical Engineering) studies.

All the information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

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Certificate of Recommendation

The thesis entitled 'Effect of UV Pretreatment on Drying Kinetics of Grapes' prepared under the supervision of Dr. Prasanta Kumar Biswas by Bivan Paul (Class Roll No. 002110902005, Registration No. 160269 of 2021-22), a student of M. Tech final year, has been evaluated by us and found satisfactory. It is therefore being accepted for the partial fulfillment of the requirement for awarding the degree of Master of Technology in Food Technology and Biochemical Engineering.

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Certificate of Approval

This is to certify that Bivan Paul has carried out research work entitled "UV Pretreatment of grapes and its effect on its Drying Kinetics'' under my supervision in the Department of Food Technology and Biochemical Engineering, Jadavpur University, Kolkata. I am satisfied that he has carried out this work independently and with care and confidence. I hereby recommend that this dissertation be accepted in partial fulfillment of the requirements for the degree of Master of Technology in Food Technology and Biochemical Engineering.

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EFFECT OF UV PRETREATMENT ON DRYING KINETICS OF GRAPES.

CONTENTS

Objective of Study

- Study the drying rate kinetics of Grapes: To understand the drying rate and characteristics of grapes, during drying. Such information has relevance with industrial use and possible technical interventions.
- Replacement of chemical pre-treatment of drying: As evident in present scenario, the consumer preference has shifted towards food which are clean label and contains as little chemical pre-treatments, preservatives or additives.
- Use of UV as a mode of pre-treatment for drying: UV has become popular due to its antimicrobial and phytosanitary properties. The use of UV as a mode of pretreatment for drying grapes will be studied.
- Understanding and using of mathematical model to find the best fit for drying kinetics of UV-pretreated grapes at different UV exposure.

1.Grapes and its Varieties

A grape is the fruit of a vine of the genus Vitis, and is one of the most important fruit crop in the world due to its nutritional and therapeutic value. Grapes are good source of dietary sugars, organic acids and some vitamins. The seedless raisins are called as Kishmish which not only provides sweetness but also dietary fibres, some amount of minerals and vitamins. Raisins are dried grapes, and grapes do not become raisins until their moisture content is reduced (Pawar & Pawar, 2020). Raisin colors can vary as a result of the different drying processes; a dark purple or black raisin is sundried, a light brown raisin is mechanically dehydrated, and yellow raisins are mechanically dried and treated with sulfur dioxide.

Major grape-growing states are Maharashtra, Karnataka, Tamil Nadu, and Mizoram. Maharashtra ranks first in terms of production accounting for more than 70 % of total production and the highest productivity in the country during 2021-22 (3rd Advance Estimate). Karnataka is the second largest producer of Grapes with a share of 25% in 2021-22 (3rd Advance Estimate). More than 20 varieties are under cultivation in India. However, only a dozen are commercially grown (APEDA). They can be grouped under the following 4 categories, based on color and seeds

Coloured seeded	Bangalore Blue, Gulabi (Muscat)
Coloured seedless	Beauty Seedless and Sharad Seedless
White seeded	Anab-e-Shahi, Dilkhush (clone of Anab-e-Shahi
White seedless	Perlette, Pusa Seedless, Thompson Seedless, and its clones Tas-A-Ganesh, Sonaka and Manik Chaman

From the ancient times to now, grape has been one of the most valued conventional fruit varieties. In fruits and vegetables phytochemicals play vital roles in reducing chronic disease risk. Grapes are one of the most popular and widely cultivated and mostly consumed fruits in the world. The usefulness of grapes is increasing day to day due to unique natural gifted products not only for the development of valuable medicines against a number of diseases, but also for manufacturing various industrial products. Grape is either consumed fresh, processed into beverages, jam, and jelly, or dried to produce raisins. Grapes used for fresh consumption mainly include *V. vinifera* seedless grape cultivars, which are characterized by large-sized berries, high sugar content, mild flavor, and thin skin (Pawar & Pawar, 2020).

A majority of the grapes produced worldwide are crushed for wine production. Red wine is consumed in larger quantities than white wine. The United States is the largest wine consumer in the world followed by France and other European countries. A number of seeded and seedless grape cultivars are grown worldwide for the production of raisins. Raisin production consists of drying ripened grapes under natural conditions for 2–4 weeks until a change in color and significant decrease in moisture content occur. Drying emulsions are used to accelerate the drying process. Sulfur dioxide is generally used during raisin production to prevent browning and preserve natural flavor and health beneficial compounds. 'Thompson Seedless' is most widely used for raisin production followed by other cultivars including 'Fiesta,' 'Zante currant,' 'DOVine,' and 'Muscat of Alexandria.' (Doymaz, 2016).

Grape juice quality is governed by several factors including cultivar, management and harvesting procedures, and postharvest handling and processing. Processing of grapes to produce juice involves a hot-press or cold-press method where the crushed grapes are heated to 60–63 °C or used at room temperature for treating with pectinolytic enzymes to break down the pectins. Crushed and treated juice, and pulp, undergo further processing for obtaining the final product. Differences in yield and quality are observed between the two processing techniques. Grape juice concentrate is made by evaporating and concentrating grape juice to achieve 55–68% total soluble solids (TSS). Grape juice concentrate is used in fruit cocktails and as a sweetener in other food products (Roberts & Kidd, 2008). A substantial amount of juice concentrate is made from 'Thompson Seedless' in addition to the other cultivars. Other processed products include jam, jelly, and fruit spreads. Grape seed extract is rich in a number of phenolic antioxidants and available as a dietary supplement in the form of capsules and liquid extract (Roberts & Kidd, 2008).

Export Potential for Grapes and Resins

Farming is the most significant segment of the Indian economy contributing significantly to the country's GDP and employment opportunity in rural areas. While half of the populace is still reliant on agriculture for the vast majority of their livelihoods, comprehensive development cannot be achieved without proper selling avenues. Globalization of world trade has opened up tremendous open entryways for multifold increase in acceptance of Indian things. Agribusiness, which shapes over 33% of the money related activity of the country, provides for tapping this potential in the field of cultivation (Pawar & Pawar, 2020). Grape is a natural product, organically a berry, of the deciduous woody vines of the blooming plant family Vitis. Grapes are developed since ancient occasions. The worldwide grape creation right now adds up to more than 75.8 million tons (Mt) as indicated by Food and Agriculture Organization and International Organization of Vine and Wine (OIV) information for 2019. The world's five biggest grape producers are: China (about 14.5 Mt), Italy (about 7.9 Mt), United States of America (about 7.1 Mt), France (about 6.4 Mt) and Spain (about 6.0 Mt). Around 71% of this creation is bound for wine making, while the rest of expended new as table grapes and squeeze or dried as raisin (Zemni, Sghaie Khiari, Khiari, & Chebil, 2017).

Grape is a significant business organic product yield of India, which adds to the greatest offer among the new foods grown from the ground sent out to Europe and different pieces of the world. As per the gauge of NHB, the absolute zone and creation of grapes in the year 2016-17 was 136.0 thousand hectares and 2.6833 million tons, separately. Significant grape developing states are Maharashtra, Karnataka, Andhra Pradesh, Tamil Nadu and the North-Western area covering Punjab, Haryana, western Uttar Pradesh, Rajasthan and Madhya Pradesh. In India, raisins are principally delivered in Sangli, Solapur and Nasik locale of Maharashtra and Vijayapur area of Karnataka state (Venkatram, Padmavathamma, & Sankar, 2017). India holds significant export potential for grapes and raisins due to its diverse agro-climatic conditions, extensive cultivation, and improving agricultural practices. Both products have garnered international attention for their quality, taste, and versatility, positioning India as a key player in the global market.

Grapes

India is among the world's largest producers of grapes, with a wide range of grape varieties grown across various regions. The country has a competitive advantage due to its ability to produce grapes for both table consumption and wine production. The export potential of Indian grapes is substantial due to several factors

1. Geographical Diversity: India's diverse climate allows for year-round grape production, giving it a competitive edge in the global market where demand exists even during off-seasons in other grape-producing countries.

2. Varietal Range: India cultivates a diverse range of grape varieties, including Thompson Seedless, Sonaka, Flame Seedless, and Red Globe. This variety allows exporters to cater to different tastes and preferences worldwide (Pawar & Pawar, 2020).

3. Quality and Taste: Indian grapes are known for their sweetness, flavor, and overall quality. This is a crucial factor that appeals to international consumers seeking premium and unique grape varieties.

4. Modern Agricultural Practices: The adoption of advanced agricultural practices, including precision farming, improved irrigation techniques, and pest management, has enhanced grape quality and consistency, making Indian grapes more competitive in the global market (APEDA).

5. Export Infrastructure: India has been investing in post-harvest infrastructure, cold storage, and transportation facilities, ensuring that grapes reach international markets in good condition, maintaining their quality and shelf life (APEDA).

Raisins

Indian raisins, derived from grapes, are another product with significant export potential due to their health benefits, natural sweetness, and versatility in various cuisines. Some key factors contributing to the export potential of Indian raisins include:

1. Organic and Natural Appeal: Indian raisins are often produced using traditional drying methods, making them appealing to health-conscious consumers looking for organic and natural products.

2. Nutritional Value: Raisins are rich in dietary fiber, antioxidants, and essential vitamins, making them a popular choice for healthy snacking and as ingredients in various food products (Venkatram, Padmavathamma, & Sankar, 2017).

3. Culinary Use: Indian raisins find applications in both sweet and savory dishes, including baked goods, breakfast items, desserts, and traditional Indian dishes. This versatility increases their demand in international markets.

4. Global Health Trends:With increasing awareness about the health benefits of dried fruits like raisins, there is a growing demand for such products in various countries. Indian raisins are well-positioned to tap into this trend (APEDA).

5. Competitive Pricing: Indian raisins are often competitively priced compared to those from other countries, making them attractive to international buyers.

6. Export Infrastructure: As with grapes, the investment in post-harvest infrastructure and quality control measures for raisins has improved their export potential by ensuring consistent quality and reducing post-harvest losses.

To fully realize the export potential of grapes and raisins, India has to focus on ensuring product quality, adhering to international food safety standards, and effectively marketing its products to target markets. Additionally, efforts to streamline export procedures, address logistical challenges, and provide relevant market information to growers and exporters will contribute to the growth of the grape and raisin export sector.

3.Drying and its advantages

3.1.a.Background of Drying

The preservation of foods by drying is the most common method used by humans and the food processing industry. Dehydration of food is one of the most important achievements in human history, making humans less dependent upon a daily food supply even under adverse environmental conditions. Though in earlier times drying was dependent on the sun, nowadays many types of sophisticated equipment and methods are used to dehydrate foods. During the past few decades, considerable efforts have been made to understand some of the chemical and biochemical changes that occur during dehydration, and develop methods for preventing undesirable quality losses. Foods can be divided into three broad groups based on the value added through processing by drying (Rahman, 2008). In the case of cereals, legumes, and root crops, not much value is added by drying operation. But, much value is added to foods such as fruits, vegetables, meats and fish. It is considerably higher for high-value crops such as spices, herbs, medicinal plants, nuts, bioactive materials and enzymes (Senadeera, Adiletta, Di Matteo, & Russo, 2014) (Mercado & Gongora, 2001).

b.Mode of Preservation

Drying reduces the water activity, thus preserving foods by avoiding microbial growth and deteriorative chemical reactions. The effects of heat on microorganisms and the activity of enzymes are also important in the drying of foods. In the case of foods to be preserved by drying, it is important to maximize microorganism and enzyme inactivation for preventing spoilage and enhancing safety, and reduce the components responsible for the deterioration of the dried foods. Also, in the case of drying bacterial cultures, enzymes, or vitamins, minimum inactivation of the microorganism and enzyme is required. Thus, detrimental effects of drying may be desirable or undesirable, depending on the purpose of the drying process.

c.State of Water in Foods

The terms dried and dehydrated are not synonymous. The U.S. Department of Agriculture lists dehydrated foods as those with no more than 2.5% water (dry basis), while the term dried foods applies to any food product with more than 2.5% water (dry basis) (Mercado & Gongora, 2001). The concept of bound water and free water has bee developed from drying principles, and it is important for dried products – for its stability during processing and storage. A product containing no water is termed as bone-dry. Water exists in foods in different forms or states. In foods, water having properties different from those of pure water can be defined as bound water.

In the literature, different forms of bound water are defined, unfreezable, immobile,monolayer, and nonsolvent water. However, the fraction of bound water depends on its definition and the measurement technique used (Rahman, 2008). The binding energy of different states of bound water affects the drying process, since it requires more energy to remove bound water than free water.

d. End Point of Drying

Equilibrium in drying system is the ultimate endpoint for the process. Water activity is commonly used to estimate the equilibrium point in the case of thermal- and osmotic-drying processes. In mechanical dewatering, the magnitude of the applied force and rheological properties of the foods affect the equilibrium point. Generally meat, fish, and dairy products are dehydrated to a moisture content of 3% or less, vegetable products usually to 5%, and cereal products frequently to as much as 12% (Rahman, 2008). A maximum moisture level is usually established for each dried product separately, based on the desired quality after drying and during storage. Different attributes of quality can be targeted; thus, the endpoint should be determined from all aspects, such as safety first and then consumer acceptance.

e. Heating Methods in Drying

Heating air using flue gas is the conventional heating method used for drying foods. In this case, heat transfer from the gas to the product occurs mainly through convection. The heating method is another important aspect of drying, in terms of quality as well as energy cost. Microwave, infrared, radio frequency, refractance window, and dielectric heating use electromagnetic wavelength spectrum as a form of energy, which interacts with the materials, thus generating heat and increasing the drying rate dramatically. Dielectric drying uses frequencies in the range of 1–100 MHz, whereas microwave drying uses frequencies in the range of 300-300,000 MHz. Microwave heating is rapid, more uniform in the case of liquids, and more energy efficient than the hot-air method (Decareau, 1985). Applying microwave energy under vacuum affords the advantages of both vacuum drying and microwave drying, thereby providing improved energy efficiency and product quality. The energy can be applied in pulsed or continuous mode; however, pulsed microwave drying is more efficient than continuous drying.

3.2.a.Drying Methods

Drying processes can be broadly classified, based on the water-removing method applied, as
(a) thermal drying,
(b) osmotic dehydration, and
(c) mechanical dewatering.

In thermal drying, a gaseous or void medium is used to remove water from the material. Thus, thermal drying can be divided further into three types: (a) airdrying,

(b) low air environment drying, and
(c) modified atmosphere drying.

In osmotic dehydration, a solvent or solution is applied to remove water, whereas in mechanical dewatering physical force is used.

Consideration should be given to many factors before selecting a drying process. There is no one best technique of drying that is applicable for all products. The factors of consideration are:
(a) the type of product to be dried,
(b) desired properties of the finished product,
(c) allowable temperature tolerance,
(d) the product's susceptibility to heat,
(e) pretreatments required,
(f) capital and processing costs, and
(g) environmental factors.

3.2.b.Thermal Drying

Thermal drying is one of the most widely used methods of drying foods. In this process, heat is mainly used to remove water from the foods. The mechanisms of moisture transfer depend mainly on the types or physicochemical state of food materials and the drying process.
Food materials can be classified as:
(a) homogeneous gels, (b) porous materials with interconnecting pores or capillaries, and (c) materials having an outer skin that is the main barrier to moisture flow (Mercado & Gongora, 2001). The type or structure of foods always plays an important role in the drying process.

3.3.a.Drying Fundamentals

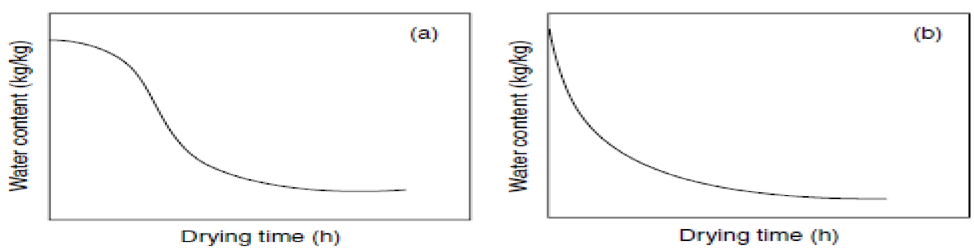
In terms of transport phenomenon, it is considered as both heat and mass transport process inside and outside of the food materials. Hence there are two resistances: heat transfer and mass transfer. During the constant rate period, it is considered that there exists a thin film of water on the slice and there is no internal or external mass transfer resistance. Hence, drying is controlled by external heat transfer. In the falling rate period, drying is controlled by the internal mass transfer resistance. The absence of a constant rate period indicates that the drying is controlled from the beginning by internal mass transfer resistance. The moisture content at the point when the drying period changes from a constant to a falling rate can be considered as the critical moisture content. The critical moisture content depends on the characteristics of the food and the drying conditions. The critical moisture contents varied from 0.78 to 0.83 (kg/kg, wet basis) for vegetables and 0.85 to 0.89 (kg/kg, wet basis) for fruits (Saravacos, 1992).
At high moisture content, liquid flow due to capillary forces dominates. At decreasing moisture content, the amount of liquid in the pores also decreases and a gas phase is built up, causing a decrease in liquid permeability. Gradually, the mass transfer is taken over by vapor diffusion in a porous structure. At the saturation point, liquid is no longer available in the pores and mass transfer is taken over completely by vapor diffusion.
The moisture is transferred from the solid materials by diffusion or capillary mechanism. In diffusion mechanism, the concentration gradient is the driving force. Water diffusion can be in the form of liquid or vapor. In the case of liquid diffusion, osmotic pressure could be the driving force for water movement.

In capillary mechanism, the moisture moves due to surface tension and does not conform to the laws Of diffusion. A porous material contains a complicated network of interconnecting pores and channels extending to the exterior surface. As water is removed, a meniscus is formed across each pore, which sets up capillary forces by the interfacial tension between the water and the solid. Capillary forces act in a direction perpendicular to the surface of the solid. The strength of capillary forces at a given point in a pore depends on the curvature of the meniscus, which is a function of the pore cross section. Small pores develop greater capillary forces than large ones; thus, large pores tend to empty their water content first. In large pores, the capillary forces are small. The force of gravity is large in comparison with the capillary forces, and there is a directional effect due to gravity (McCabe & Smith, 2003).

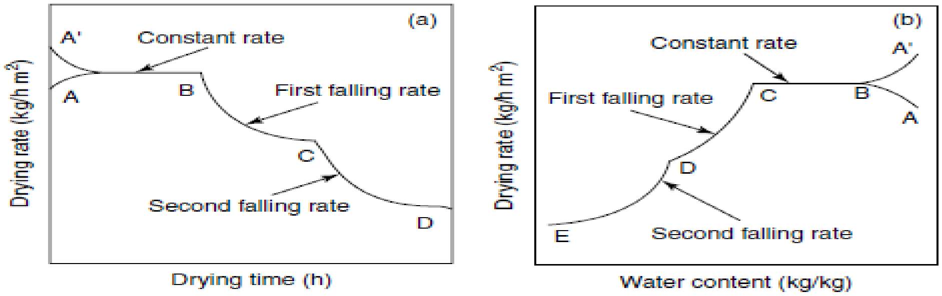
3.3.b. Drying Curve

Drying curve usually plots the drying rate versus drying time or moisture contents. Three major stages of drying can be observed in the drying curve:
1. Transient early stage, during which the product is heating up (transient period)
2. Constant or first period, in which moisture is comparatively easy to remove (constant rate period)
3. Falling or second period, in which moisture is bound or held within the solid matrix (falling rate period)

The moisture content at which the change from the first to the second period occurs is known as the critical moisture content. Typically, two falling rate periods are observed for both hygroscopic and non hygroscopic solids (Rahman, 2008). The first falling rate period is postulated to depend on both internal and external mass transfer rates, while the second period, during which drying is much slower, is postulated to depend entirely on internal mass transfer resistance. The slower rate may be due to the solid–water interaction or glass–rubber transition .The drying behaviors of food materials depend on the porosity, homogeneity, and hygroscopic properties. The immediate entrance into the falling rate is characteristic of hygroscopic food materials.



3.1 Typical drying curves (water content versus drying time): (a) with a lag period, (b) without a lag period.



3.2 Typical drying rate curves: (a) drying rate versus drying time, (b) drying rate versus water content.

3.4 Air-Drying Methods

In the case of air drying, atmosphere is used as the drying medium and heat as different modes could be applied in the process.

3.4.a Sun Drying

Earlier, only sun drying was used for drying. In this process, foods are directly exposed to the sun by placing them on the land or left hanging in the air. The main disadvantages of this type of drying are (i) contaminations from the environment, (ii) product losses and contaminations by insects and birds,(iii) floor space requirements, (iv) difficulty in controlling the process, and (v) bad odor. When the climate is not particularly suitable for air drying or better quality is desired, mechanical air drying is mainly used. However, sun drying is the cheapest method of drying foods. Nowadays, solar and mechanical air drying is widely used commercially.

3.4.b Solar Drying

Solar drying is an extension of sun drying that uses radiation energy from the sun. Solar drying is a nonpolluting process and uses renewable energy. Moreover, solar energy is an abundant energy source that cannot be monopolized . However, solar drying has several drawbacks that limit its use in large-scale production. These are the need for large areas of space and for high labor inputs, difficulty in controlling the rate of drying, and insect infestation and microbial contamination.More options in designing are now available in the literature in order to avoid or reduce the above difficulties.

3.4.c. In-Store Drying

In-store drying can also be called low-temperature in-bin drying. It may be used when grains are stored until milled or sold. Weather conditions in tropical climates are less favorable for in-store drying, due to high ambient temperatures and relative humidity values. Two-stage drying can produce good quality by preventing discoloration of high-moisture grains and reduced cracking of skin dry kernels.

3.4.d. Convection Air Drying

Cabinet- and bed-type dryers (i.e., kiln, tray, truck tray, rotary flow conveyor, and tunnel) fall into the first generation [144]. This is the simplest drying technique, which takes place in an enclosed and heated chamber. The drying medium, hot air, is allowed to pass over the product, which has been placed in open trays. Convection drying is often a continuous process and is mostly used for products that are relatively low in value. Air drying is usually accomplished by passing air at regulated temperature and humidity over or through the food in a dryer. Factors that affect the rate of drying are temperature, humidity, air velocity and distribution pattern, air exchange, product geometry and characteristics, and thickness. The sample is usually placed on mesh trays in one layer or in bulk on a bed or hung from a string for better air circulation over the product. Air circulation can be horizontal or vertical to the layer or bed. The structure and composition, such as fat content, of a product affects the drying rate. In general, the hotter is the air temperature,the faster is the drying rate; and similarly, the higher is the velocity, the higher is the drying rate; the lower is the air humidity, the higher is the drying rate. The relative humidity (a measure of dryness) is lower when air temperature is raised. A dryer must expel air to get rid of moisture, thereby allowing new, lower humidity air to enter the system. However, this process causes heat loss from the dryer.

3.4.e Explosive Puff Drying

Explosive puff drying uses a combination of high temperature and high pressure, and a sudden release of the pressure (explosion) to flush superheated water out of a product. This method gives a product of good rehydrability. However, the high heat can degrade food quality, and the explosion puffing may compromise product integrity.

3.4.f Spray Drying

Spray drying is used to remove water from a free-flowing liquid mixture, thus transforming it into a powder form. The fluid to be dried is first atomized by pumping it through either a nozzle or a rotary atomizer,thus forming small droplets with large surface areas. The droplets immediately come into contact with a hot drying gas, usually air. The liquid is very rapidly evaporated, thus minimizing contact timeand heat damage. Disadvantages include the size of the equipment required to achieve drying is very large and very oily materials might require special preparation to remove excessive levels of fat before atomization [25]. Ultrasonication in the chamber can be used instead of complex atomization to produce small-diameter droplets in spray drying.

3.4.g Fluidized Bed Drying

This technique involves the movement of particulate matter in an upward-flowing gas stream, usually hot air.Fluidization mobilizes the solid particulates, thus creating turbulences on the solid surfaces, which increases the drying rate. The hot gas is introduced at the bottom of a preloaded cylindrical bed and exits at the top. In some cases, a vibratory mechanism is used to increase the contact of the product with the hot gas. Fluidized bed drying is usually carried out as a batch process and requires relatively small, uniform, and discrete particles that can be readily fluidized [25]. The main advantages of fluidized bed drying are uniform temperature and high drying rates, thus less thermal damage. A rotating chamber is also used with the fluidized bed, thus increasing centrifugal force to further increase the drying rate and mixing. The use of a solid carrier, such as sea sand, and wheat bran could prevent the biomaterial from deterioration due to thermal shock.

3.4.h Ball Drying

In this method, the material to be dried is added at the top of the drying chamber through a screw conveyor. The material within the drying chamber comes into direct contact with heated balls made from ceramic or other heat-conductive material. Drying occurs primarily by conduction. Hot air is passed through the bottom side of the chamber. When the product arrives at the bottom of the chamber, it is separated from the balls and collected .

3.4.i Rotary Drum Drying

Rotary drum dryers are cylindrical shells 1–5 m in diameter, 10–40 m in length, and rotating at 1–8 rpmwith a circumferential speed of approximately 0.2–0.4 m/s. These conditions depend on the product types to be dried. The dryers are designed to operate at a nearly horizontal position, inclined only by 2°–6° to maintain the axial advance of solids, which are fed from the upper end of the dryer body .

3.4.j Drum Drying

This technique removes water from a slurry, paste, or fluid that has been placed on the surface of a heated drum. The dryer may comprise either a single or a double drum. Drum drying is typically a continuous operation, and care must be taken to ensure that the product that is to be dried adheres well to the drying surface; in some cases, it may be necessary to modify the liquid product by using additives to change its surface tension or viscosity .

4.Quality characteristics of dried food

4.1 Selection of Variety

Optimum freshness plays an important role in determining the quality and stability of dried foods, fresher the raw material, more stable and better is the quality of the product. Suitable varieties of produce with the desired maturity should be used to achieve a product that is best in quality (Chang & Su, 2006). The quality characteristics of dried foods can be grouped as microbial, chemical, physical, and nutritional.

Microbial	Chemical	Physical	Nutritional
Pathogen Spoiling Toxin	Browning Oxidation Color loss Aroma development Removal of undesired components	Rehydration Solubility Texture Aroma loss Porosity Shrinkage Crust formation Structure	Vitamin loss Protein loss Functionality loss Fatty acid loss

Table 4.1 Quality characteristics of dried food.

4.2 Browning Reactions

Browning reactions change color, decrease nutritional value and solubility, create off-flavors, and induce textural changes. Browning reactions can be classified as enzymatic or non enzymatic, with the latter being more serious as far as the drying process is concerned. The two major types of non enzymatic browning are caramelization and Maillard browning. In addition to moisture level, temperature, pH, and composition are the other parameters that affect the rate of non enzymatic browning. The rate of browning is most rapid in the intermediate moisture range and decreases at very low and very high moistures. Browning tends to occur primarily at the center of the drying period. This may be due to the migration of soluble constituents toward the center. Browning is also more severe near the end of the drying period, when the moisture level of the sample is low and less evaporative cooling is taking place that causes the product temperature to rise. Several suggestions were found to help reduce browning during drying. In all the cases, it was emphasized that the product should not experience unnecessary heat when it is in its critical moisture content range.

Maillard-type nonenzymatic browning reactions in processed meat products also contribute to the product's external surface color. The main browning reaction involves the reaction of carbonyl compounds with amino groups, although lesser amounts of carbonyl browning also occur. Muscle usually contains small amounts of carbohydrates in the form of glycogen, reducing sugars, and nucleotides, while the amino groups are readily available from the muscle proteins. Browning occurs at temperatures of 80°C–90°C and increases with time and temperature . A loss of both amino acids and sugars from the tissue occurs as a result of the browning reaction. Lysine, hystidine, threonine, methionine, and cysteine are some of the amino acids that may become involved in browning.

4.3 Lipid Oxidation

Dehydrated foods containing fats are prone to develop rancidity after a period, particularly if the water content is reduced too much. Fish oils or fats are more unsaturated than beef or butter, and they are usually classified as drying oils because they contain considerable proportions of highly unsaturated acids. The behavior of drying oils toward atmospheric oxygen is well known, and oxidation is a serious problem for commercial drying of fatty fish and seafood. The flesh of some fatty fish, such as herrings, contains a fat pro-oxidant that is not wholly inactivated by heat. Lipid oxidation is responsible for rancidity, development of off-flavors, and the loss of fat-soluble vitamins and pigments in many foods, especially in dehydrated foods.

4.4 Structural Changes

Structural changes in food during drying are usually studied by microscopy. Microscopy provides a good tool to study this type of phenomenon as well as other types of physical and chemical changes during the drying of food materials. Shrinkage occurs first at the surface and then gradually moves to the bottom as the drying time increases. The cell walls became elongated. As drying proceeds at high temperature,cracks are formed in the inner structure. Osmotic treatment prior to vacuum drying and other such pretreatments alongwith synergistic drying technique can preserve the cellular structure by keeping intact their three-dimensional nature.

4.5 Case Hardening or Crust Formation

During drying, the concentration of moisture in the outer layers of foods is less than in the interior, since the outer layers necessarily lose moisture before the interior. This surface shrinkage causes checking, cracking, and warping. This type of shrinkage causes moisture gradient and resistance near the surface. In extreme cases, shrinkage and drop in diffusivity may combine to yield a skin practically impervious to moisture, which encloses the volume of the material so that the interior moisture cannot be removed. This is called case hardening. In food processing, case hardening is also commonly known as crust formation. The extent of crust formation can be reduced by maintaining flattening moisture gradients in the solid, which is a function of drying rate. The faster the drying rate, the thinner the crust (Saravacos, 1992). Crust (or shell) formation may be either desirable or undesirable in dried food products. In microencapsulation of flavors, rapid crust formation is required to prevent flavor losses. The crust formation may be inhibited by allowing the drying rate to be slow enough that moisture loss from the product surface is replenished by moisture from the inside. Crust formation is also important in explosion puffing. In this case, the high-moisture product is exposed to rapid drying conditions such as high temperature and vacuum, which create a crust. The impermeable crust, coupled with the extreme drying conditions, results in rapid moisture vaporization and causes large internal pressures to build up, resulting in product expansion/puffing. During the expansion stage, stress buildup in the glassy surface may cause the surface to crack, allowing vapor to escape.

4.6 Shrinkage or Collapse and Pore Formation

Two types of shrinkage are usually observed in the case of food materials—isotropic and anisotropic shrinkage. Isotropic shrinkage can be described as the uniform shrinkage in all geometric dimensions of the materials. Anisotropic shrinkage is described as the non uniform shrinkage in the different geometric dimensions. In many cases, it is important to estimate the changes in all the characteristic geometric dimensions to characterize a material. In most fruits and vegetables the isotropic shrinkage takes place. Shrinkage is an important phenomenon impacting dried food product quality by reducing product wettability, changing product texture, and decreasing product absorbency. Depending on the end use, crust and pore formation may be desirable or undesirable (Senadeera, Adilettta, Di Matteo, & Russo, 2014). If a long shelf life is required for cereal product then crust of that product which prevents moisture reabsorption is generally preferred. For products such as dried vegetables in instant noodles, where good rehydration capacity is required, high porosity with no crust is desired.

Glass transition theory is one of the proposed concepts to explain the process of shrinkage and collapse during drying and other related processes. According to this concept,there is negligible collapse (more pores) in the material if processed below glass transition and higher the difference between the process temperature and the glass transition temperature, the higher the collapse. The methods of freeze drying and hot-air drying can be compared based on this theory.

4.7 Stress Development and Cracking or Breakage

During air drying, stresses are formed due to non uniform shrinkage resulting from non uniform moisture and temperature distributions. This may lead to stress crack formation when stresses exceed a critical level. Crack formation is a complex process influenced interactively by heat and moisture transfer,physical properties, and operational conditions (Liu & Zhou, 2007). The relative humidity of air and temperature are the most influential parameters that need to be controlled to eliminate the formation of cracks. Cracking is detrimental to grain quality since the affected kernels are more susceptible to mold attack during storage and pathogenic invasion after seeding.

4.8 Color Retention or Development

High temperature and long drying time degrade a product's original color. Color in foods can be preserved by minimal heat exposure or applying high temperature and short time with pH adjustment. Water activity is one of the important factors degrading chlorophyll. Another cause of color degradation may be due to enzymatic browning causing rapid darkening, mainly of the leafy portions. The formation of dark pigments via enzymatic browning is initiated by the enzyme polyphenol oxidase(PPO). Another reason for discoloration is photooxidation of pigments, caused by light in combination with oxygen.

5.Pretreatment before drying and its effect

Pretreatments are done so as to aid the process of drying. It make the sample suitable for the next unit operation, which may be to preserve the sample quality, reduction in time of unit operation or even both. For drying, various pretreatments are done, which are explained below:

5.a Blanching

Pretreatments are common in most of the drying processes in order to improve product quality, storage stability, and process efficiency. In recent years, an improvement in quality retention of the dried products by altering processing strategy and pretreatment has gained much attention. Blanching is a process of preheating the product by immersion in water or steam. The main purpose of blanching is to inactivate the naturally occurring enzymes present in foods, since enzymes are responsible for off-flavor development, discoloration or browning, deterioration of nutritional quality, and textural changes in food materials. Other advantages are that it removes air-bubbles from vegetable surfaces and from intercellular spaces, reduces the initial microbial load, cleans raw food materials initially, facilitating preliminary operations such as peeling and dicing, and improving color, texture and flavor under optimum conditions. Blanching may have disadvantages, for example, it may change the texture, color, and flavor because of the heating process as it increases the loss of soluble solids, such as vitamins (Rahman, 2008). Hence, (Eliot & Bolin, 1998)time and temperature of blanching are the important factors for achieving optimum quality of the dried product.

5.b Sulfur Dioxide Treatment

Sulfur dioxide preserves the texture, flavor, vitamin content, and color that make food attractive to the consumer. Sulfur dioxide treatment is used widely in the food industry to reduce the fruit-darkening rate during drying and storage, and preserves ascorbic acid and carotene. Sulfur dioxide taken up by the foods displaces air from the tissue in plant materials, softens cell walls so that drying occurs more easily, destroys enzymes that cause darkening of cut surfaces, shows fungicidal and insecticidal properties, and enhances the bright attractive color of dried fruits (Eliot & Bolin, 1998). Permitted levels of sulfur dioxide and other additives (solutes) in dried foods vary from country to country. Sulfur dioxide in dried fruits is set at the highest level by food legislation. The allowed limit is 2000 mg/kg of dried fruit. Sulfiting treatment can be done by burning sulfur or soaking foods in sulfite solution. Gaseous sulfur dioxide can be produced by burning sulfur with oxygen in the air and then circulating it to the smoking chamber. Potential advantages in using a bisulfate solution are (Eliot & Bolin) decreased air pollution, better control of the sulfuring process, greatly shortened sulfuring time, and decreased desorption losses during drying.

The chemical reactions of sulfur dioxide when it is added to fruits and other food products are complex. Sulfite could be bound or free in the food matrix. The bound sulfite is considered to have no retarding effect on product deterioration; thus, it is important to know the factors that influence binding (Eliot & Bolin, 1998). The amount of bound sulfite depends on pH; carbonyl groups of aldehydes, acetaldehyde, pyruvic acid and the availability of oxygen, sugars, and starch. Sulfiting and blanching can also be used together for pretreatment . A number of factors may affect sulfur dioxide uptake by fruits and vegetables, including concentration and temperature of dipping solution, time of dipping, geometry and conditions of sample (i.e., peeled or unpeeled, whole or sliced), and agitation of solution (Eliot & Bolin, 1998).

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5.c Salting or Curing

Salting or curing is a natural type of osmotic dehydration. Curing was originally developed to preserve certain foods by the addition of sodium chloride. In the food industry, the application of curing is related only to certain meat, fish, and cheese products. Today sodium chloride, and sodium and potassium nitrite (or nitrate) are considered as curing salts. Salting is one of the most common pretreatments used for fish products. It converts fresh fish into shelf-stable products by reducing the moisture content and acting as a preservative. In combination with drying, these processes contribute to the development of characteristic sensory qualities in the products, which influence their utilization as food (Rahman, 2008).

5.d Other Dipping Pretreatments

Dipping pretreatment with chemicals is generally used in addition to blanching, sulfite treatment. The dipping treatment is a process of immersion of foods in a solution containing additives. Usually, the concentration level is below 5% and the dipping time below 5 minutes, whereas osmotic dehydration is carried out at higher concentrations and for long processing times. The main purpose of the dipping treatment is to improve the drying characteristics and quality. Certain chemicals are used to enhance the rate of dehydration . Among these compounds, methyl and ethyl oleate, or olive oil are the most common (Weitz, Lara, & Piacentini, 2003). Methyl oleate has realized the greatest usage because of economics and its higher taste threshold. A carbonate-oleate combination has superior when used alone in accelerating drying rate. A synergistic effect results from the combined use of alkali accelerated. carbonates and methyl oleate for drying. When excess carbonate is used, drying iss further accelerated. Esters affect the waxy surface of fruits by altering the physical arrangement of the surface wax platelets, thus allowing moisture to more readily evaporate from the fruit.

	Chemicals Used for dipping Treatment	
Chemicals	Type	Compounds
	Esters	Methyl oleate,ethyl oleate, butyly oleate
	Salts	Patassium carbonate, sodium carbonate, sodium chloride, potassium sorbate
	Organic acids	Oleic acid, steric acid, caprilic acid, tartaric acid, oleanolic acid.
	Oils	Olive oil
	Alkali	Sodium hydroxide
	Wetting agents	Pectin
	Others	Sugar, liquid pectin
Surfectants	Nonionic	Monoglycerides,diglycerides, alkylated aryl polyester alcohol, D-sorbitol, polyoxyethylene
	Anionic	Sodium oleate, stearic acid,sorbitan heptadecanyl sulphate

Table 5.d.1 Chemicals Used for dipping Treatment (Rahman, 2008)

5.e Freezing Pretreatment

Freezing treatment affects the drying process. The rehydration rate of air and vacuum-dried fruits and vegetables subjected to freezing treatment increased to a level comparable with that of freeze-dried products. It was also noticed that the longer the duration of freezing, the better the rehydration kinetics of dried products. This was due to the formation of large ice crystals by slow freezing. Drying rate iss not dependent on the pressure in the drying chamber—ranging between 20 and 50 mm Hg, and above 50 mm Hg the drying rate decreased rapidly with pressure.

6.Current pretreatment and drying methods of Grapes

Grapes being an important horticultural crop with significant commercial value, continues to be processed for various end products, such as resins, wine, etc. From, the drying point of view, there exists various methods of drying and its corresponding pretreatment. This depends on the available resources, cost economics, climatic conditions and the desired quality attributes of final product.

6.a Open drying

Grapes pre-treated are spread on a platform in a thin layer directly exposed to the sun. During sun drying process, part of the solar radiation penetrate the material and be absorbed within the grape itself, thus generating heat in the interior of the material as well as at its surface, therefore, increasing the heat transfer and enhances moisture evaporation. Usually time required in open drying is between 6 to 9 days depending on the weather conditions. (Pawar & Pawar, 2020).

6.b Shade drying

Shade drying is also a kind of natural method and extensively used for grape drying. It is also known as natural rack dryer. Pre-treated grapes are placed on the rack of dimension of 250*150*30 cm3 and capacity of 500kg. (Pawar & Pawar, 2020) The air is the principal source of heat required for drying. Raisin of shade drying obtained better colour than sun drying, avoid the directly contact with sun rays. Time required in shade drying is between 12 to 15 days depending on the weather conditions.

Fig 6.b.1 Shade Drying of Grapes (Pawar & Pawar, 2020)

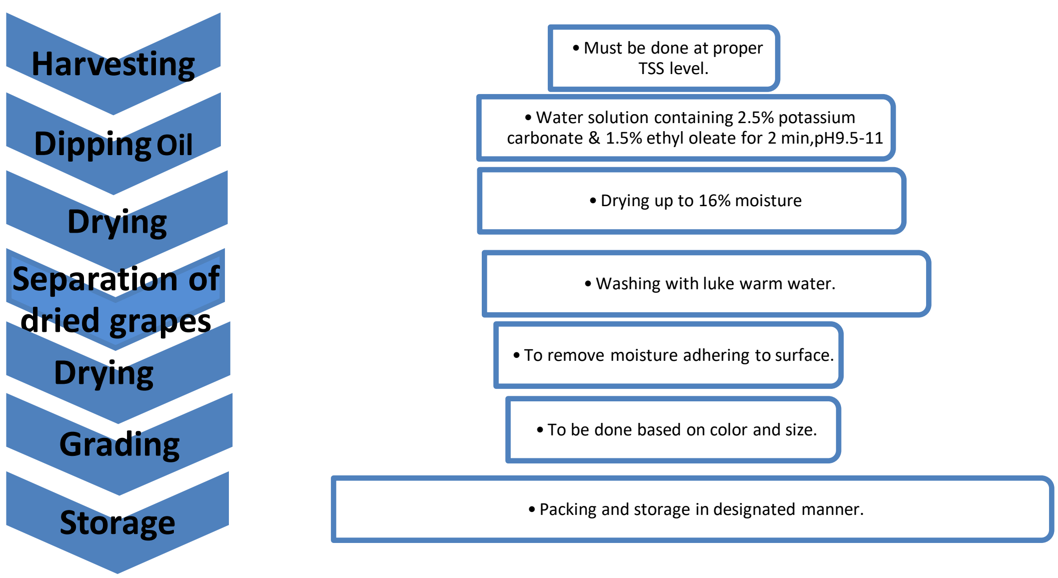


Fig 6.1 Flowchart of conventional drying process. (Pawar & Pawar, 2020)

6.c Controlled shade drying

It is same as a shade drying where temperature and humidity are controlled as per the requirement. In controlled shade drying, the sensors are placed with heater and air blower. The sensors starts on low temperature range and stops when it reaches to higher temperature set as per the requirement. The temperature and humidity were set in the range of 30-42ºC and 6-20%.The dimensions of controlled shade drying cabinet were 250*150*30 cm3 and capacity of 500kg. Time required in controlled shade drying is between 10 to 13 days depending on the inner cabinet conditions.

6.d Tray drying

In this type of drying tray drier were used, which consisted of three basic section- an air blowing section, air heating section, and a drying chamber. The drying compartment consisted of trays, placed perpendicularly to the airflow. The grapes were placed in a single layer over the tray and inserted into the dryer cabinet, after operating conditions had been achieved. The tray containing samples was weighted at regular interval time drying runs were carried out at a constant temperature and air velocity. The temperature kept in tray drying was 35ºC The dimension of tray was 80*40 cm2 and capacity of 25kg. Time required in tray drying is between 3 to 5 days (Pawar & Pawar, 2020).

7.UV as a mode of pretreatment for drying

Drying is one of the most important methods of food preservation aiming at the reduction of moisture content to a safe level, at which microbial spoilage and moisture-mediated deteriorative reactions are minimized. Drying of food material also facilitates the reduction of weight and volume that minimizes packing, storage, and transportation expenditures. The most common drying approach is hot air drying, but it has several limitations, such as long drying time, degradation of heat-sensitive compounds, and high energy consumption. However, literature proves that pretreatments before hot air drying can reduce the drying time and protect the nutrients from oxidative and thermal degradation. With this regard, chemical pretreatments are frequently employed (Yemmireddy & Adhikari, 2022). The challenging issue is that chemical pretreatments in food products can induce food safety concerns.

Ultraviolet (UV) light processing of foods is a nonthermal technology used to enhance the quality and safety of foods. Its uses range from sanitization of foods (primary use) to extension of shelf life of fruits and vegetables, and enhancement of phytochemical content in fruits (Forouzanfar & Hojjati, 2020)

The UV spectrum of radiation includes of wavelengths between 200 and 400 nm,which can be divided into UVA (315 to 400 nm), UVB (280 to 315 nm) and UVC (200 to 280 nm). UV systems can deliver energy in a single wavelength (monochromatic UV systems) or a broader range of wavelengths. UV light systems provide very high-intensity radiation in a broad spectrum, which can consist of UVA, UVB, UVC and visible light (percentages of each range depends on the type of lamp used).

UV treatment is currently in use by the industry primarily in the sanitization of fruit and vegetables. Many studies reported on the effects of UV light on fruit juices and leafy vegetables. These studies reported that UV light also contributed towards the enhancement of the nutritional quality of food products, enhancing vitamin content, total carotenoids content, antioxidant capacity and other phytochemical properties (Yemmireddy & Adhikari, 2022).

The application of UV to a solid matrix, such as whole foods or fruit cuts is still under investigation and poses a more difficult problem because large tissue particulates block or scatter UV radiation. Thus, its suitability must be better evaluated. Therefore, alternative pretreatment approach is essential to improve the quality characteristics of dried specimen in together with desired drying characteristics, such as higher drying rate (DR), less time-consuming, and minimum power consumption. Non-chemical pretreatments, such as blanching, ultrasound, pulsed electric field, far-infrared radiation, and abrasion of the peel were also reported in several studies.
UV pretreatment in drying involves using ultraviolet (UV) light to treat materials before they undergo the drying process. UV pretreatment can have several benefits, such as reducing the moisture content in the material, sterilizing surfaces, and enhancing adhesion properties for coatings or inks. UV light can break down certain chemical bonds, making it easier to remove moisture or contaminants during the drying process that follows (Braga & Silva, 2018). This technique is commonly used in industries like printing, coatings, and electronics manufacturing. But it has become relevant in food due to its non-chemical approach and other phyto-sanitary benefits.

Alternatively, cold plasma (CP) is a non-thermal treatment and novel technology, which consists of ionized gases, including different electrons, ions, and reactive neutral species. Myriad of studies reported that CP involves exposing food to ionizing radiation, which can efficiently disinfect microbes, inactivate enzymatic reactions, improve product quality, and ensure the safety of the products. In recent, CP approach has newly been applied as a pretreatment to explore the effects of direct CP on drying kinetics, microstructure, and quality attributes of different food items, in terms of color parameters, pigment content, and antioxidant activity. According to the outcomes, CP was capable of improving the drying kinetics and quality attributes. On the contrary, several studies reported that direct application of CP to a food product can induce color loss, degradation of bioactive compounds, and changes in surface topography. However, the lack of information on the application of CP as a pretreatment to investigate the drying kinetics of agro-products demands further exploration. Cold plasma-activated water (CPAW) could be another suitable and alternative pretreatment, in which CP can indirectly affect the sample. The overall effect of CPAW was observed as similar to CP.

Thus, before delving in to use of CP, use of UV as a mode of pre-treatment requires extensive study, owing to its ease and mode of use.

8.Energy consumption in drying and cost economics associated on pretreatment

Drying is a crucial process in the food industry that extends the shelf life of various products, preserves their nutritional value, and enhances their flavors. However, the drying process often consumes a significant amount of energy, which can lead to higher operational costs and environmental concerns. To mitigate these challenges, pretreatment methods are employed to improve the efficiency of drying, leading to cost savings and reduced energy consumption.

Energy consumption in the drying of food is influenced by several factors, including the type of food being dried, the drying method used, and the level of moisture removal required. Conventional drying methods, such as hot air drying, involve the application of heat to remove moisture from the food. This process demands substantial energy inputs, primarily for heating the drying air. Advanced drying technologies, like vacuum drying and freeze drying, can be more energy-efficient but often require higher initial investments.

The cost of energy in the drying process constitutes a significant portion of the overall production expenses. Therefore, optimizing energy consumption is vital for both economic and environmental reasons. One approach to reducing energy consumption is the implementation of pretreatment techniques before drying. Pretreatment involves preparing the food product in a way that accelerates the drying process and minimizes energy requirements. Several pretreatment methods yield economic benefits while also preserving the quality of the final product.

Pretreatment processes commonly applied in food drying include blanching, osmotic dehydration, and enzymatic treatment. Blanching, which involves a brief exposure to high temperatures, inactivates enzymes, softens tissues, and improves water mobility within the food. As a result, subsequent drying times and energy consumption can be significantly reduced. Osmotic dehydration, where food is soaked in hypertonic solutions to remove moisture, can lower drying times and energy usage while enhancing flavor concentration. Enzymatic treatments can break down cell structures, facilitating easier moisture removal and potentially reducing drying time and energy demand.

The cost economics associated with pretreatment before drying are multifaceted. While pretreatment methods might add an extra step to the overall process, their benefits often outweigh the costs. Shorter drying times result in reduced energy consumption and operational costs. Furthermore, improved product quality due to reduced exposure to high temperatures can lead to higher market value and customer satisfaction. However, the economic viability of pretreatment depends on factors such as the specific food product, the scale of production, and the availability of resources.

It's crucial to consider not only the direct costs of pretreatment but also the potential savings and increased revenue resulting from improved drying efficiency and enhanced product quality. Conducting a thorough cost-benefit analysis for each pretreatment method is essential to make informed decisions.

In conclusion, energy consumption in the drying of food is a significant concern in terms of both cost and environmental impact. Pretreatment methods offer a viable solution to mitigate these challenges by reducing drying times, improving energy efficiency, and enhancing product quality. While there are associated costs with implementing pretreatment processes, the potential benefits in terms of energy savings, reduced operational costs, and improved product value make them a promising avenue for the food industry. As technology advances and sustainability becomes more critical, optimizing drying processes through pretreatment will continue to play a pivotal role in the future of food production

9.Discussion on studies on Pretreatment of Drying

Pretreatment of drying, a crucial process in various industries, has gained significant attention in recent studies due to its potential to enhance the efficiency and quality of drying operations. Pretreatment involves subjecting materials to certain treatments or modifications before the actual drying process, aiming to improve drying rates, reduce energy consumption, and maintain the desired product characteristics. This discussion highlights some key findings from recent studies in the field of pretreatment of drying. One area of study focuses on the use of pretreatment methods to alter the physical and chemical properties of materials, thereby influencing their drying behavior. Researchers have investigated techniques such as blanching, osmotic dehydration, and impregnation with solutes (Zemni, Sghaie Khiari, Khiari, & Chebil, 2017). For instance, blanching, which involves a brief exposure to high temperatures, can inactivate enzymes that cause degradation and color changes in fruits and vegetables during drying. Osmotic dehydration, on the other hand, involves immersing materials in hypertonic solutions to remove water and enhance porosity, thus accelerating subsequent drying.Another aspect of pretreatment research revolves around the application of electromagnetic fields (EMFs) prior to drying. Studies suggest that EMFs can facilitate the movement of water molecules within the material, reducing the energy required for evaporation. This approach has shown promise in drying agricultural products and polymers. Researchers are exploring the optimal frequency and intensity of EMFs for different materials to maximize drying efficiency. Furthermore, the integration of pretreatment with novel drying technologies has garnered attention. Combining pretreatment with techniques such as microwave drying, freeze drying, and supercritical fluid drying can lead to synergistic effects. For example, pretreating food products with ultrasound before microwave drying can enhance the overall drying rate and improve product quality by reducing moisture gradients within the materia (Decareau, 1985).

Recent research also delves into the impact of pretreatment on energy consumption during drying. By altering the material structure or moisture content through pretreatment, the energy required for subsequent drying stages can be reduced. This is particularly relevant in industries where energy efficiency is a critical concern, such as in the pharmaceutical and food sectors. In the context of environmental sustainability, pretreatment has shown potential in reducing waste generation during drying. By modifying the material's structure, pretreatment can lead to reduced cracking, shrinkage, and deformation during drying, minimizing product losses. This aligns with the growing emphasis on reducing food waste and enhancing resource utilization.

However, challenges and complexities exist in the widespread adoption of pretreatment in drying processes. The selection of appropriate pretreatment methods depends on factors like material type, desired product quality, and economic feasibility. Additionally, the scalability and cost-effectiveness of these techniques remain areas of exploration. The pretreatment of drying underscore its significance in improving drying efficiency, energy consumption, and product quality across various industries. Whether through physical or chemical modifications, electromagnetic fields, or integration with advanced drying technologies, pretreatment holds promise for revolutionizing drying processes. As researchers continue to unravel the intricacies of pretreatment methods and their synergies, the field is poised for advancements that could redefine the landscape of drying technology.

Sl No.	**Title**	**Major Outline**	**Reference**
1	Drying of Mangoes (*Mangifera indica* L.)	Mangoes were subjected to pulses of UV light and dried in a convective	(Braga & Silva, 2018)

	applying Pulsed UV Light as Pretreatment	oven-drier. The pulsed UV light pretreatment reduced the water content in the samples and increased retention of carotenoids. (Braga & Silva, 2018)	
2.	Drying kinetics of black grapes treated with different solutions	Effect of various chemical pre-treatments, drying kinetics and other associated effects. Grapes dipped in ethyl oleate plus potassium carbonate solution, were found to have shortest drying time (Doymaz, 2016).	(Doymaz, 2016)
3.	Influence of UV Pretreatments on Kinetics of Convective Hot Air Drying Mushrooms (Agaricus bisporus)	The effect of UV pretrteatment on selected physical properties and drying kinetics of mushrooms was studied. As per the study,Henderson–Pabis model could be used as a tool for the prediction of drying time (Forouzanfar & Hojjati, 2020).	(Forouzanfar & Hojjati, 2020)
4.	Drying kinetics of grape seeds	Convective hot air drying was used. The three thin-layer models were used to predict the drying curves, Page model, Lewis model, and the Henderson–Pabis model. All three models were found to produce accurate predictions (Doymaz, 2016).	(Roberts & Kidd, 2008)
5.	Experimental and modelling study of thin layer drying kinetics of pellets millet flour	The thin layer drying kinetics of pellets millet flour was studied. Ten thin layer drying models were evaluated by fitting the experimental moisture data. The goodness of fit of each model was evaluated using the coefficient of determination (Bassene, Gaye, Talla, & Sambou, 2013).	(Bassene, Gaye, Talla, & Sambou, 2013)
6.	Drying Kinetics, Quality Changes and Shrinkage of Two Grape varieties of Italy	The study shows that drying occurs at falling rate period. Treated grape showed reduced drying times due to faster release of moisture. This may be attributed to the lower resistance offered for diffusion of moisture through the skin due to physical treatment (Senadeera, Adilettta, Di Matteo, & Russo, 2014).	(Roberts & Kidd, 2008)
7.	Drying kinetics of cap and stem of mushroom	Thin-layer drying of cap and stem of mushroom was studied. Drying took place in the falling rate period, and the drying behaviour was adequately described by the Page's equation (Addo, Bart-Plange, & Boakye, 2015).	(Addo, Bart-Plange, & Boakye, 2015)

10. Discussion on studies on Drying Kinetics of Food materials

Studies on the drying kinetics of food materials have been a focal point in food science and engineering due to its crucial implications on product quality, energy efficiency, and overall process optimization. Drying kinetics refers to the study of how moisture is removed from food products over time, and it plays a significant role in understanding the drying behavior of different food materials. This discussion delves into key findings and aspects of recent studies related to the drying kinetics of food materials. One of the fundamental areas of investigation in drying kinetics is the determination of drying curves. These curves depict the relationship between the moisture content of the food material and the drying time. Researchers have employed various mathematical models, such as the Page model, the Henderson and Pabis model, and the Logarithmic model, to fit experimental drying data and predict moisture content changes accurately. These models aid in estimating critical drying parameters like drying rate constants and effective moisture diffusivities, offering insights into the behavior of food materials during drying. Moreover, researchers have examined the influence of external factors on drying kinetics, such as temperature, relative humidity, and airflow velocity (Senadeera, Adiletta, Di Matteo, & Russo, 2014). Temperature is a critical parameter as it affects the rate of moisture evaporation. Studies often highlight the importance of selecting appropriate drying conditions to achieve rapid drying while minimizing undesirable effects such as color change and nutrient degradation. Understanding the interplay between these factors and drying kinetics contributes to the development of optimized drying processes (Roberts & Kidd, 2008).

The exploration of different drying methods has also been a focus of recent studies. Convective drying, microwave drying, vacuum drying, and freeze drying are among the methods investigated for their impact on drying kinetics. For instance, microwave drying can significantly alter drying kinetics due to its ability to heat the material volumetrically, leading to rapid moisture migration and non-uniform drying within the product. Such studies contribute to identifying the most suitable drying method for specific food materials based on their characteristics and desired product quality. Another intriguing aspect is shrinkage and its effects on drying kinetics. As food materials lose moisture, they often undergo physical changes such as shrinkage, which can affect the internal moisture diffusion pathways. Recent studies have employed digital imaging techniques and mathematical modeling to better understand the relationship between shrinkage, pore structure changes, and drying kinetics. This understanding is essential for predicting the overall drying behavior accurately.

In recent years, there has been a growing emphasis on the application of novel technologies, such as artificial intelligence and machine learning, to predict and model drying kinetics. These approaches offer the potential to enhance our understanding of complex drying processes and to develop predictive models that can account for a wider range of variables. However, challenges persist in studying drying kinetics. Variability in the initial moisture content, particle size, and porosity of food materials can impact drying kinetics, making it necessary to adapt models to specific scenarios. Additionally, accurately measuring moisture content during drying presents technical challenges that researchers continually work to overcome. Studies on the drying kinetics of food materials have provided invaluable insights into the intricate processes that occur during drying. By employing mathematical models, investigating the effects of external factors, exploring different drying methods, and considering the impact of physical changes like shrinkage, researchers are advancing our understanding of drying kinetics. This knowledge contributes to the development of efficient, high-quality drying processes that are essential for preserving the nutritional value and sensory attributes of food products.

Various mathematical model for drying kinetics (Bassene, Gaye, Talla, & Sambou, 2013):

1	**Newton**	MR= exp(-kt)	Shen et al. (2011), Evin (2011), Meziane (2011), Akpinar et al.(2008)
2	**Page**	MR= $\exp(-kt^n)$	Flores et al. (2012) ,Radhika et al.(2011), Shen at al.(2011), Evin (2011), Meziane (2011) , Doymaz (2008) , Akpinar et al.(2008)
3	**Henderson and Pabis**	MR= a exp(-kt)	Flores et al. (2012) , Radhika et al. (2011), Shen et al. (2011), Evin (2011), Meziane (2011) , Doymaz (2008) , Akpinar et al. (2008)
4	**Logarithmic**	MR= a exp(-kt)+c	Radhika et al.(2011), Shen at al.(2011), Evin (2011), Meziane (2011), Doymaz (2008) , Akpinar et al.(2008)
5	**Two-term**	MR=a $\exp(-k_0t)$+b $\exp(-k_1t)$	Flores et al.(2012) , Shen at al.(2011), Evin (2011), Meziane (2011), Akpinar et al.(2008)
6	**Diffusion approach**	MR=a exp(-kt)+ (1-a) exp(kbt)	Flores et al. (2012) , Meziane (2011), Akpinar et al. (2008)
7	**Modified Henderson and Pabis**	MR= a exp(-kt)+ b exp(-gt)+c exp(-ht)	Evin (2011), Meziane (2011), Akpinar et al. (2008)
8	**Two term exponential**	MR= a exp(-kt)+(1-a)exp(-kat)	Shen at al.(2011), Evin (2011)
9	**Wang and Sing**	MR=$1+at+bt^2$	Flores et al. (2012) , Radhika et al(2011), Shen et al. (2011), Meziane (2011), Doymaz (2008)
10	**Midilli et al**	MR= a $\exp(-kt^n)$+bt	Evin (2011), Meziane (2011

Materials and methods

1.Sample preparation of grapes

2.Design and setup of UV-pretreatment chamber

3.Determination of Operating parameters: exposure time, drying temperature, drying time.

4.Use of mathematical model for drying kinetics

5.Calculation of effective moisture diffusivity

1.Sample preparation of grapes

Fresh grapes from local market were sourced. The grapes were gently destalked, as stalks of grapes would be having different drying characteristics from the grapes. The grapes were sorted and subdivided in to 4 parts, each weighing around 50 gm and placed on 4 square shaped Aluminium foil, with marking as Control, 15 mins, 25 mins and 30 mins were taken. Thereby using weighing balance, the initial weight of grapes were measured in 4 sets as described above.

2.Design and setup of UV-pretreatment chamber

Corrugated cardboard box was used as UV-pretreatment chamber. UV light lamp having specifications 2A/250V, 75 W, model T130/5464 was used. The UV lamp was placed in it horizontally. Before switching on the UV lamp, the set of 3 weighed grape samples in marked aluminium foil(15 min,25 min and 30 min) were placed in this box. Thereafter, the box was closed and UV lamp switched on. After 15 min,20 min and 30 min since switching on, the respective samples were taken out from the box, placed in desiccator until the next operation of drying in tray dryer.

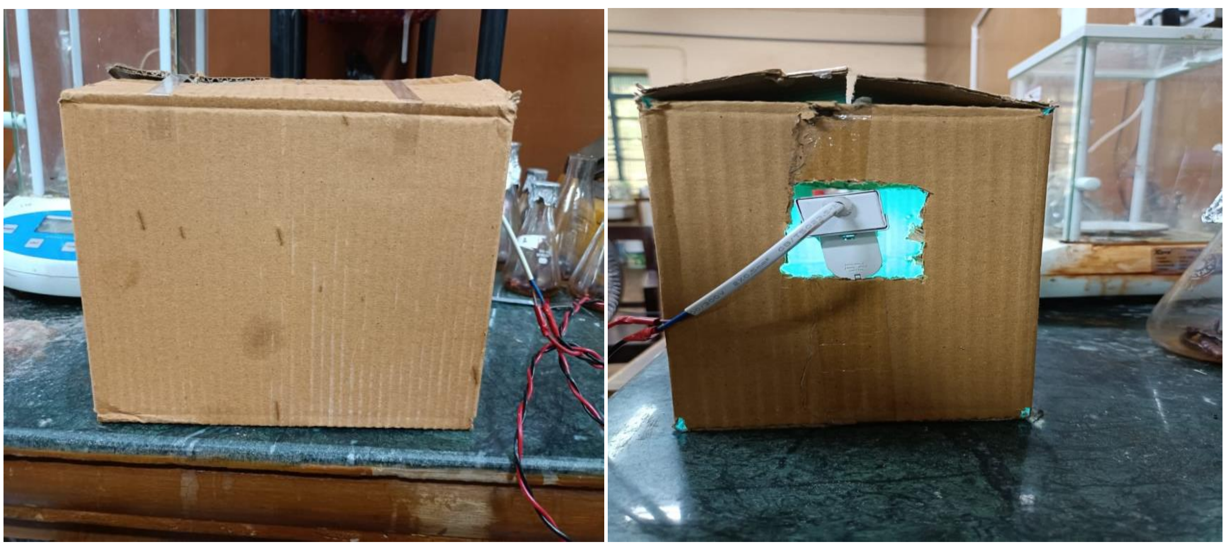


Figure 2.1 UV-pretreatment chamber.

3.Determination of Operating parameters: exposure time, drying temperature, drying time.

As per the scientific literature regarding similar work, the drying temperature considered was 60 degree Celsius. The exposure time to the ultraviolet light was 15 min,20 min and 30 min respectively. As per the available resources, the drying duration for the study was 300 minutes.

4.Use of mathematical model for drying kinetics

The initial moisture content of samples was determined by the infrared moisture analyzer (Wensar PGB 1MB), until the final weight becomes constant and calculated as the total weight of moisture loss to the total weight of sample.

The moisture content at different time intervals was calculated using the following Equation (1) assuming that the mass loss was only because of water loss during drying (Doymaz, 2016):

$$M_t = \frac{W_o M_o - (W_o - W_t)}{W_t} \times 100 \qquad (1)$$

where Mt is the moisture content (wet basis, wb) at time t, Mo is the initial moisture content (wb), Wo is the initial weight of the sample (g), and Wt is the weight of the sample (g) at time t.
Moisture ratio (MR) is calculated using Equation (2), which is reducible to Equation (3) because equilibrium moisture content (Me) is usually very low and its removal does not bring significant changes.

$$\mathrm{MR} = \frac{M_t - M_e}{M_o - M_e} \qquad (2)$$

$$\mathrm{MR} = \frac{M_t}{M_o} \qquad (3)$$

Simplified drying models have been used to quantify drying kinetics of various agro food materials (Addo, Bart-Plange, & Boakye, 2015). Mathematical models commonly applied for food materials were used as per the literature to identify the most suitable model to describe the drying behavior. The empirical model constants for the drying models were determined experimentally from normalized drying curves.

Henderson and Pabis model: MR = a exp (-kt)
Page Model: MR = exp ($-kt^n$**)**

The Microsoft Excel spread sheet was used to perform this task using the SOLVER tool using the Generalized Reduced gradient (GRG) method. The trendline was obtained, and respective equation was also obtained. The goodness of fit for the model was evaluated based on coefficient of determination (R^2).

5.Calculation of effective moisture diffusivity

Effective moisture diffusivity is a crucial parameter in understanding and controlling the moisture transfer within food products during processes like drying, baking, and storage. It quantifies the rate at which moisture moves through a food material, influencing its texture, shelf life, and overall quality. Effective moisture diffusivity is affected by factors such as temperature, humidity, and the composition of the food. A higher effective moisture diffusivity indicates faster moisture migration, which can lead to issues like uneven drying or undesirable textural changes. Conversely, a lower diffusivity might result in prolonged drying times and increased energy consumption.

Accurate determination of effective moisture diffusivity aids in optimizing process conditions, ensuring uniform drying, and preserving the sensory and nutritional attributes of the food product. It is a fundamental parameter for developing effective food processing techniques and predictive models, enabling the food industry to enhance product quality and efficiency while minimizing energy consumption and waste. For long drying times , it was demonstrated that the further simplified straight-line equation (Doymaz, 2016) can be obtained as:

$$\ln(MR) = 0.692 - (5.783\, D_{eff}/r^2)t$$

The effective moisture diffusivity was calculated using the method of slopes. It is typically determined by plotting
experimental drying data in terms of ln(MR) versus time which gives a straight line.

$$D_{eff} = -\text{Slope}\,(r^2)/5.783$$

Result and discussion

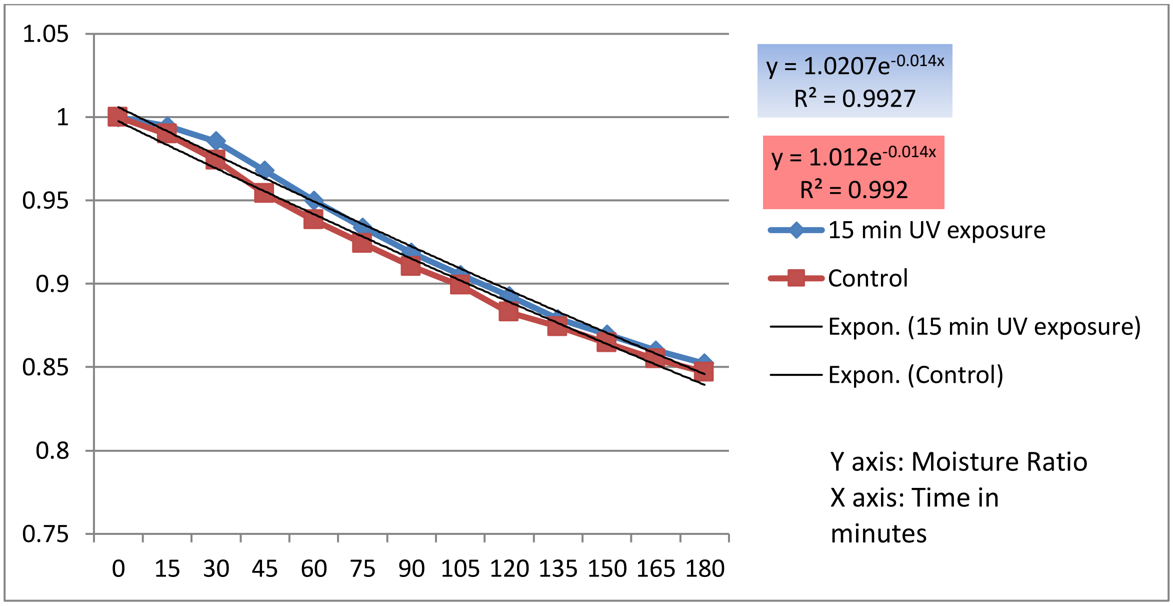
1.Drying kinetics at 15 mins pretreatment

2.Drying kinetics at 25 mins pretreatment

3.Drying kinetics at 30 mins pretreatment

1.Drying kinetics at 15 mins pretreatment

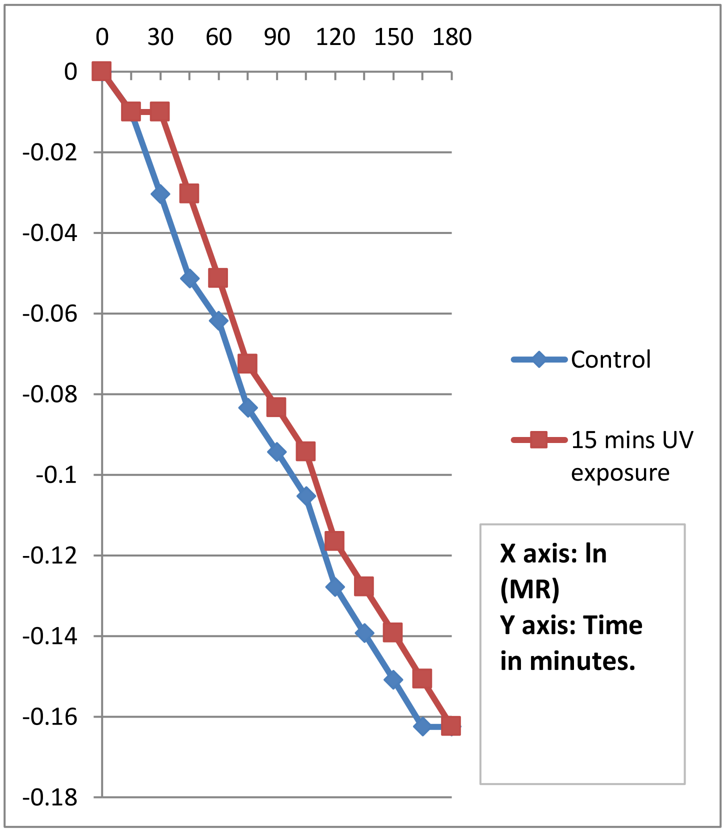
Graph has been plotted between Moisture Ratio (MR) and time in minutes from grapes samples which were exposed to UV light for 15 minutes, along with the data obtained from the control sample (which was not subjected to any UV pretreatment).



The data collected from the study, based on which the above MR vs time plot has been done, is placed below:

Minute	Control				15 min UV				
Wt of Dry matter (gm)		9.81		MR	Wt of Dry matter (gm)		9.86		
time	weight (gm)	moisture lost/kg dry mass	Mt	MR=Mt/Mo	time	weight (gm)	moisture lost/kg dry mass	Mt	MR=Mt/Mo
0	49.06	4	4	1	0	49.30	4	4	1
15	48.66	0.04	3.96	0.99	15	49.08	0.02	3.98	0.99
30	48.05	0.06	3.90	0.97	30	48.73	0.04	3.94	0.99
45	47.26	0.08	3.82	0.95	45	48.03	0.07	3.87	0.97
60	46.64	0.06	3.75	0.94	60	47.32	0.07	3.80	0.95
75	46.08	0.06	3.70	0.92	75	46.69	0.06	3.74	0.93
90	45.54	0.06	3.64	0.91	90	46.09	0.06	3.68	0.92
105	45.10	0.05	3.60	0.90	105	45.57	0.05	3.62	0.91
120	44.47	0.06	3.53	0.88	120	45.07	0.05	3.57	0.89
135	44.13	0.03	3.50	0.87	135	44.52	0.06	3.52	0.88
150	43.74	0.04	3.46	0.86	150	44.16	0.04	3.48	0.87
165	43.37	0.04	3.42	0.85	165	43.78	0.04	3.44	0.86
180	43.06	0.03	3.39	0.85	180	43.47	0.03	3.41	0.85

As mentioned earlier, effective moisture diffusivity can be obtained from the slope of the plot between ln (MR) vs time. The plotted graph is placed below.



The data collected from the study, based on which the above ln (MR) vs time plot has been done, is placed below:

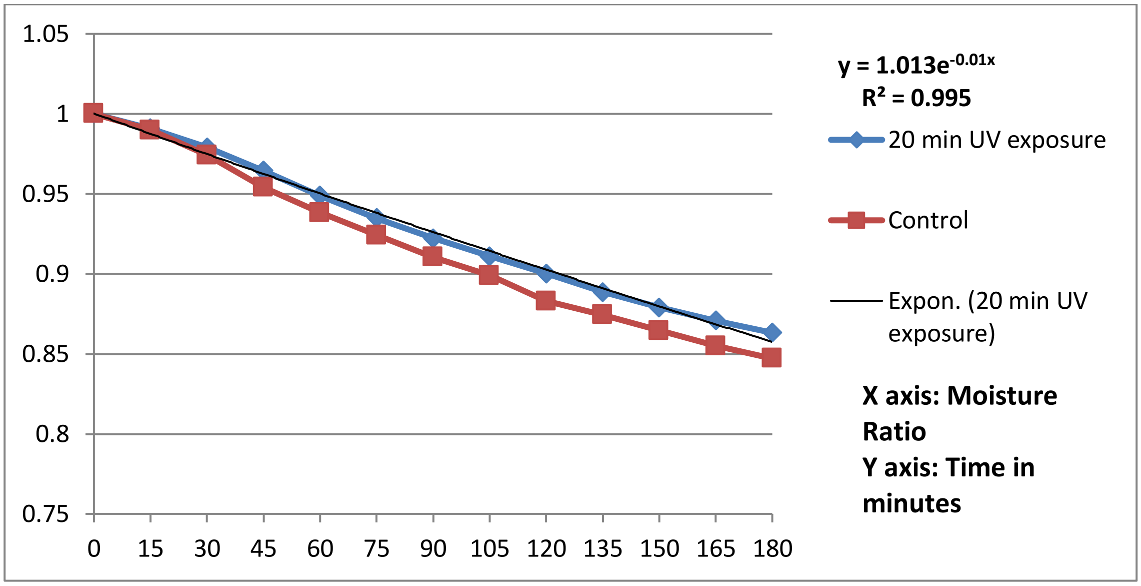
Time	Control		15 mins	
	MR	ln MR	MR	ln MR
0	1	0	1	0
15	0.99	-0.01	0.99	-0.01
30	0.97	-0.03	0.99	-0.01
45	0.95	-0.05	0.97	-0.03
60	0.94	-0.06	0.95	-0.05
75	0.92	-0.08	0.93	-0.07
90	0.91	-0.09	0.92	-0.08
105	0.9	-0.11	0.91	-0.09
120	0.88	-0.13	0.89	-0.12
135	0.87	-0.14	0.88	-0.13
150	0.86	-0.15	0.87	-0.14
165	0.85	-0.16	0.86	-0.15
180	0.85	-0.16	0.85	-0.16

The slope was calculated, and using the formula the value of D_{eff} was calculated to be 6.967x10^-9 m^2/sec, whereas D_{eff} control was 6.959x10^-9 m^2/sec.

As the D_{eff} value, is lesser than that of control, lower transportation of moisture and thereby lower drying rate. This may be attributed to the waxy outer layer of grapes, which initially on receiving UV pretreatment, could expand and act as a barrier.

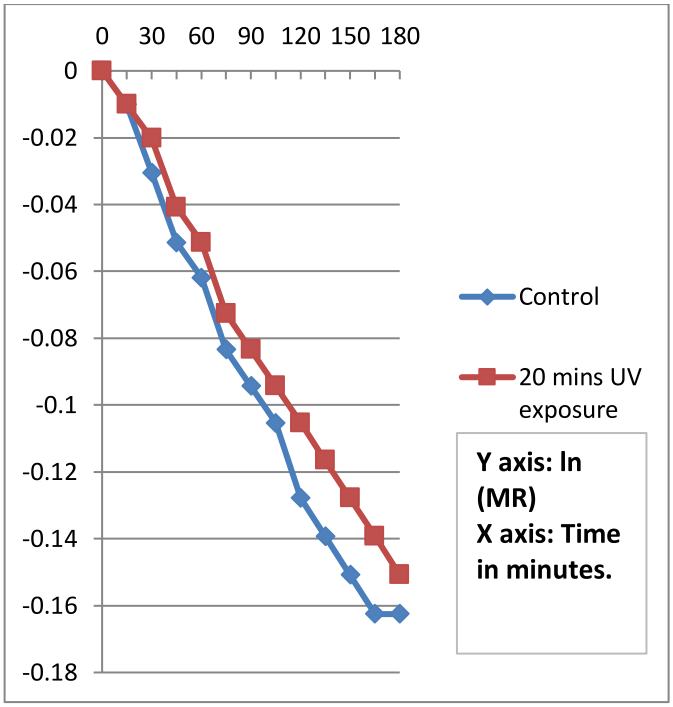
2.Drying kinetics at 20 minutes pretreatment

Graph has been plotted between Moisture Ratio (MR) and time in minutes from grapes samples which were exposed to UV light for 20 minutes, along with the data obtained from the control sample (which was not subjected to any UV pretreatment).



The data collected from the study, based on which the above MR vs time plot has been done, is placed below:

Minute	Control				25 min UV				
Wt of Dry matter (gm)		9.81		MR	Wt of Dry matter (gm)		9.64		MR
time	weight (gm)	moisture lost/kg dry mass	Mt	MR=Mt/Mo	time	weight (gm)	moisture lost/kg dry mass	Mt	MR=Mt/Mo
0	49.06	4	4	1	0	48.21	4	4	1
15	48.66	0.04	3.96	0.99	15	47.86	0.036	3.96	0.99
30	48.05	0.06	3.90	0.97	30	47.40	0.048	3.92	0.98
45	47.26	0.08	3.82	0.95	45	46.84	0.058	3.86	0.96
60	46.64	0.06	3.75	0.94	60	46.23	0.063	3.80	0.95
75	46.08	0.06	3.70	0.92	75	45.70	0.055	3.74	0.93
90	45.54	0.06	3.64	0.91	90	45.21	0.051	3.69	0.92
105	45.10	0.05	3.60	0.90	105	44.78	0.045	3.64	0.91
120	44.47	0.06	3.53	0.88	120	44.36	0.043	3.60	0.90
135	44.13	0.03	3.50	0.87	135	43.92	0.046	3.55	0.89
150	43.74	0.04	3.46	0.86	150	43.54	0.038	3.52	0.88
165	43.37	0.04	3.42	0.85	165	43.23	0.033	3.48	0.87
180	43.06	0.03	3.39	0.85	180	42.93	0.031	3.45	0.86



The data collected from the study, based on which the above ln (MR) vs time plot has been done, is placed below:

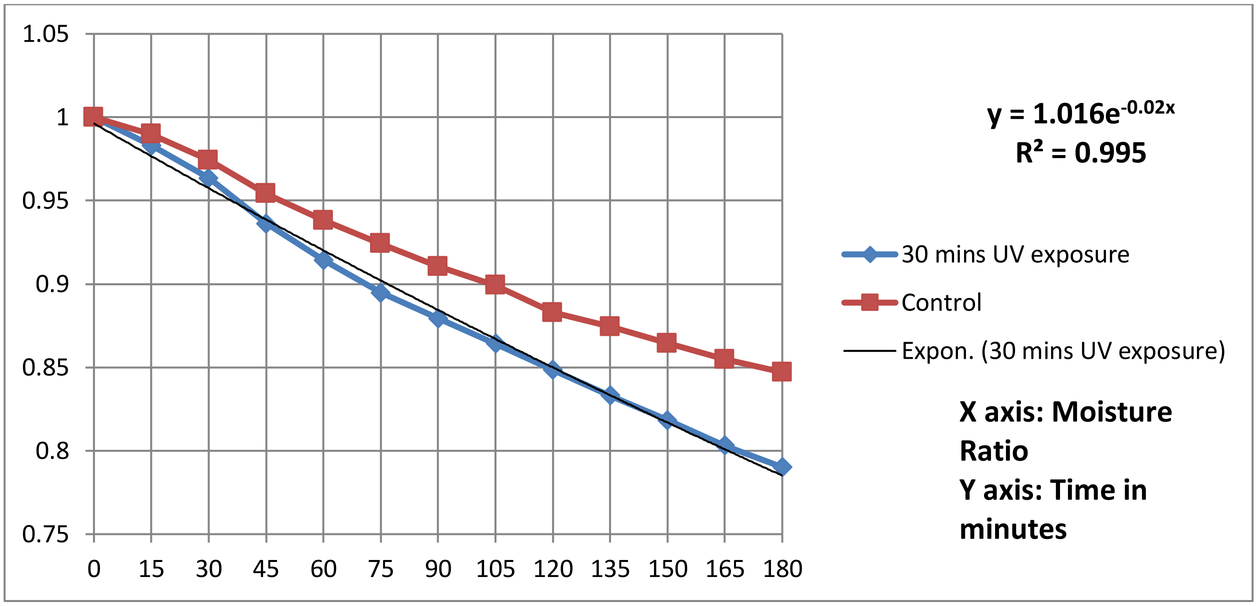
Time	Control		20 mins	
	MR	ln MR	MR	ln MR
0	1	0	1	0
15	0.99	-0.01	0.99	-0.01
30	0.97	-0.03	0.98	-0.02
45	0.95	-0.05	0.96	-0.04
60	0.94	-0.06	0.95	-0.05
75	0.92	-0.08	0.93	-0.07
90	0.91	-0.09	0.92	-0.08
105	0.9	-0.11	0.91	-0.09
120	0.88	-0.13	0.9	-0.11
135	0.87	-0.14	0.89	-0.12
150	0.86	-0.15	0.88	-0.13
165	0.85	-0.16	0.87	-0.14
180	0.85	-0.16	0.86	-0.15

The slope was calculated, and using the formula the value of D_{eff} was calculated to be 6.172*10^-9 m^2/sec whereas D_{eff} control was 6.959x10^-9 m^2/sec.

As the D_{eff} value, is lesser than that of control, lower transportation of moisture and thereby lower drying rate. This may be attributed to the waxy outer layer of grapes, which initially on receiving UV pretreatment, could expand and act as a barrier.

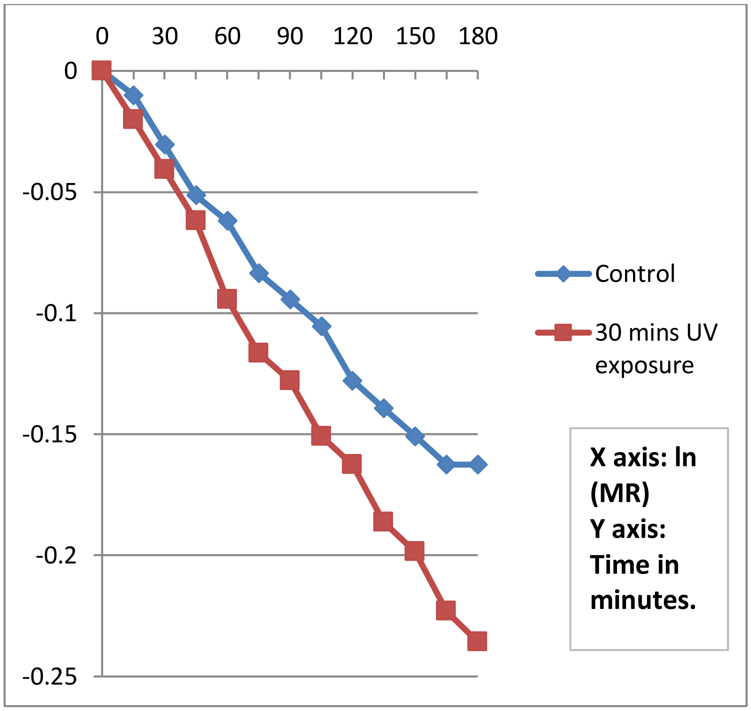
3. Drying kinetics at 30 mins pretreatment

Graph has been plotted between Moisture Ratio (MR) and time in minutes from grapes samples which were exposed to UV light for 30 minutes, along with the data obtained from the control sample (which was not subjected to any UV pretreatment).



The data collected from the study, based on which the above MR vs time plot has been done, is placed below:

Minute	Control				30 min UV				
Wt of Dry matter (gm)		9.81		MR	Wt of Dry matter (gm)		9.12		
time	weight (gm)	moisture lost/kg dry mass	Mt	MR=Mt/Mo	time	weight (gm)	moisture lost/kg dry mass	Mt	MR=Mt/Mo
0	49.06	4	4	1	0	45.61	4		1
15	48.66	0.04	3.96	0.99	15	45.00	0.07	3.93	0.98
30	48.05	0.06	3.90	0.97	30	44.28	0.08	3.85	0.96
45	47.26	0.08	3.82	0.95	45	43.29	0.11	3.75	0.94
60	46.64	0.06	3.75	0.94	60	42.49	0.09	3.66	0.91
75	46.08	0.06	3.70	0.92	75	41.77	0.08	3.58	0.89
90	45.54	0.06	3.64	0.91	90	41.21	0.06	3.52	0.88
105	45.10	0.05	3.60	0.90	105	40.66	0.06	3.46	0.86
120	44.47	0.06	3.53	0.88	120	40.09	0.06	3.39	0.85
135	44.13	0.03	3.50	0.87	135	39.52	0.06	3.33	0.83
150	43.74	0.04	3.46	0.86	150	38.98	0.06	3.27	0.82
165	43.37	0.04	3.42	0.85	165	38.43	0.06	3.21	0.80
180	43.06	0.03	3.39	0.85	180	37.96	0.05	3.16	0.79



The data collected from the study, based on which the above ln (MR) vs time plot has been done, is placed below:

Time	Control		30 mins	
	MR	ln MR	MR	ln MR
0	1	0	1	0
15	0.99	-0.01	0.98	-0.02
30	0.97	-0.03	0.96	-0.04
45	0.95	-0.05	0.94	-0.06
60	0.94	-0.06	0.91	-0.09
75	0.92	-0.08	0.89	-0.12
90	0.91	-0.09	0.88	-0.13
105	0.9	-0.11	0.86	-0.15
120	0.88	-0.13	0.85	-0.16
135	0.87	-0.14	0.83	-0.19
150	0.86	-0.15	0.82	-0.20
165	0.85	-0.16	0.8	-0.22
180	0.85	-0.16	0.79	-0.24

The slope was calculated, and using the formula the value of D_{eff} was calculated to be 9.588*10^-9 m^2/sec, whereas D_{eff} control was 6.959x10^-9 m^2/sec.

Higher the D_{eff} value, higher the transportation of moisture and thereby faster drying rate. This may be attributed to the development of cracks in the waxy layer due to appropriate level of pretreatment.

Conclusion and future work

1.Summary of Key findings: Effect of UV pretreatment of drying of Grapes

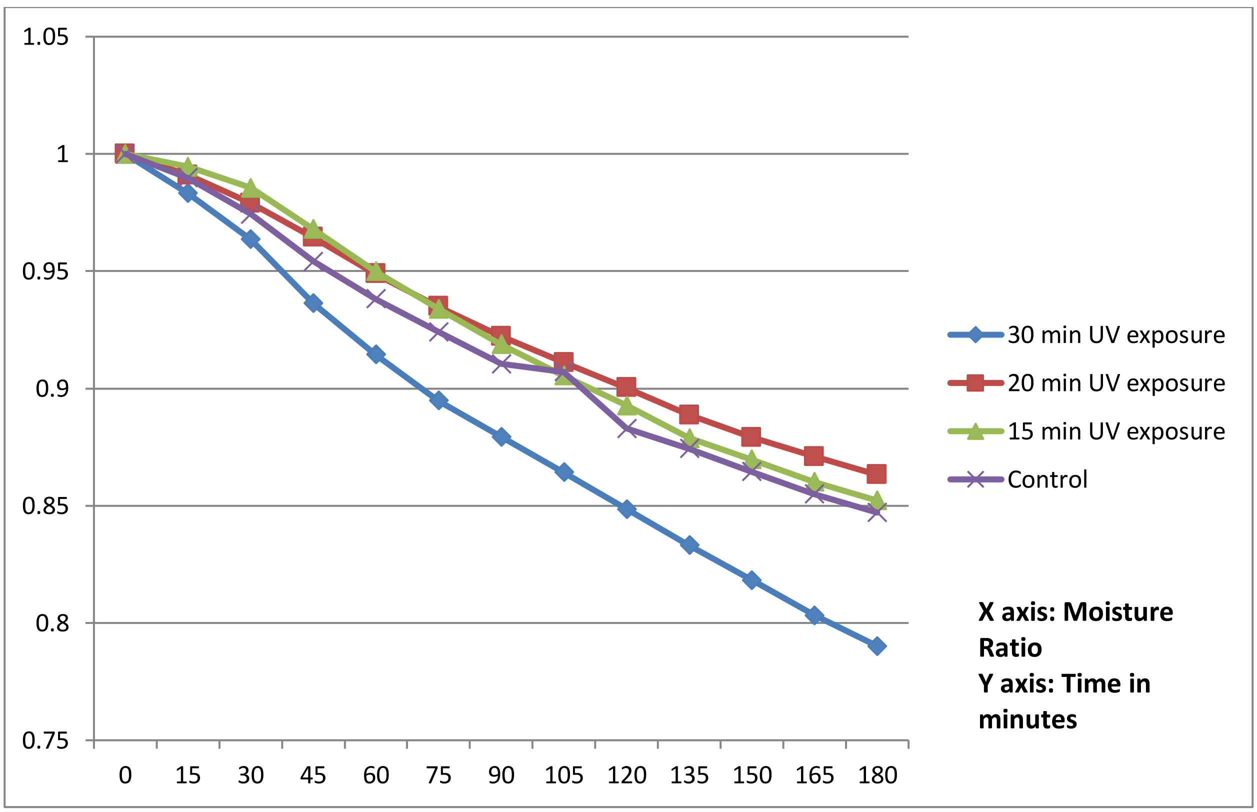
2.Scope of industrial use.

3.Further scope of Research

4. References

1.Summary of Key findings: Effect of UV pretreatment of drying of Grapes

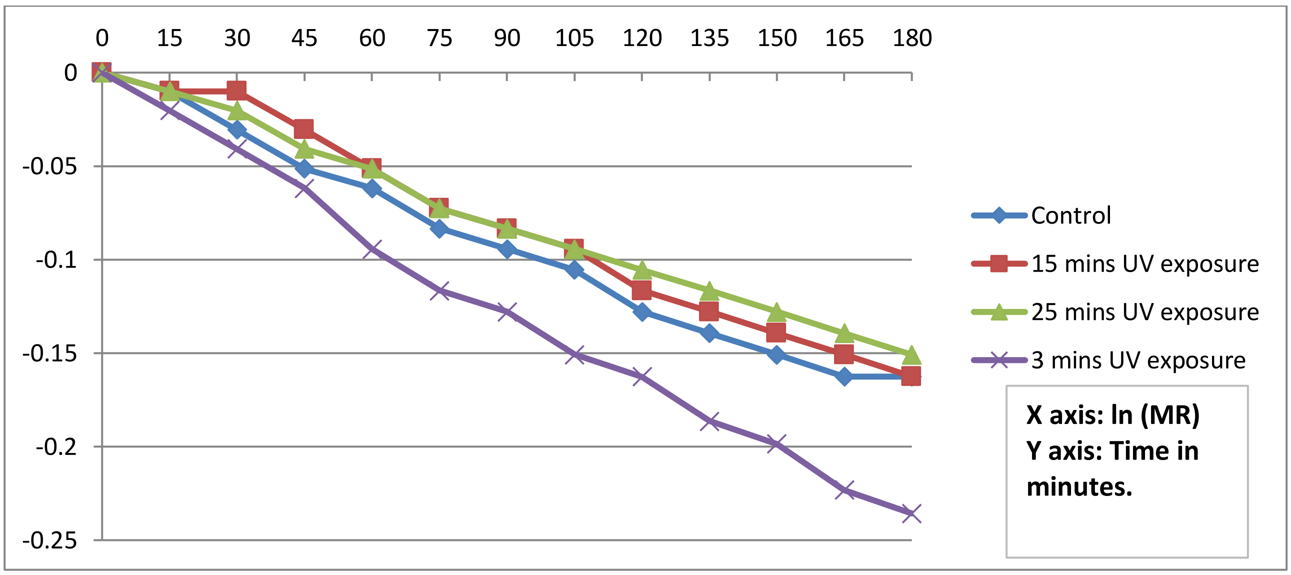
As evident from the graphical representation, the drying rate of grapes on 30 min UV pretreatment is faster than that of Control(without any UV pretreatment), 15 minute UV pretreatment and 20 minute UV pretreatment. The grapes have a waxy layer on its surface. This may serve as a barrier to moisture transport phenomenon during the process of drying. The effect of UV pretreatment on the drying kinetics of the grapes was to be studied. As per the data obtained, the drying rate decreased on 15 min UV pretreatment, when compared to the control sample. This may be attributed to the outer waxy layer on grape surface, which initially may have expanded on UV exposure. Similar phenomenon was observed on sample with 20 mins UV pretreatment. But the trend reversed with the 30 mins UV pretreatment, whereby the drying rate was faster than that of Control(without any UV pretreatment), 15 minute UV pretreatment and 20 minute UV pretreatment. This may be attributed to the development of cracks or pores on the waxy outer layer of the grapes, which in turn can aid the outwards transportation of moisture from the grapes matrix, during the drying process.



Effective moisture diffusivity is a crucial parameter in understanding and controlling the moisture transfer within food products during processes like drying, baking, and storage. It quantifies the rate at which moisture moves through a food material, influencing its texture, shelf life, and overall quality. Effective moisture diffusivity is affected by factors such as temperature, humidity, and the composition of the food. A higher effective moisture diffusivity indicates faster moisture migration, which can lead to issues like uneven drying or undesirable textural changes. Conversely, a lower diffusivity might result in prolonged drying times and increased energy consumption.

Thus, the determination of effective moisture diffusivity aids in optimizing process conditions, ensuring uniform drying, and preserving the sensory and nutritional attributes of the food product. It is a fundamental parameter for developing effective food processing techniques and predictive models, enabling the food industry to enhance product quality and efficiency while minimizing energy consumption and waste. As mentioned earlier, graph on being plotted between ln(MR) and time gives a linear plot, slope of which can be used to obtain the respective $D_{eff.}$ So as to obtain a graphical representation, of all the samples, the graph is placed below showing the relation between ln(MR) and time of the respective samples.

Sample	Control	15 mins	20 mins	30 mins
Deff (m2/s)	6.959x10^-9	6.967x10^-9	6.172*10^-9	9.588*10^-9



The data obtained suggests that the process can be described through the Henderson and Pabis model, which can be further used to predict the drying behavior. The constants, parameters, value of R^2 is placed below.

Henderson and Pabis: MR= a exp(-kt)				
Sample / Parameters	Control	15 mins UV exposure	20 mins UV exposure	30 mins UV exposure
R^2	0.992	0.992	0.995	0.995
a	1.012	1.02	1.013	1.016
k (min-1)	0.01	0.01	0.01	0.02

2.Scope of Industrial use

Grapes being an important horticultural crop with significant commercial value, continues to be processed for various end products, such as resins, wine, etc. From, the drying point of view, there exists various methods of drying and its corresponding pretreatment. This depends on the available resources, cost economics, climatic conditions and the desired quality attributes of final product. The prevalent practice in drying of grapes utilizes the chemical pretreatment.

Ultraviolet (UV) light processing of foods is a non-thermal technology used to enhance the quality and safety of foods. Its uses range from sanitization of foods to extension of shelf life of fruits and vegetables. Through this study, UV may be considered as a mode of pretreatment for drying of grapes, at appropriate exposure duration. This will thereby reduce, if not completely eliminate the use of chemical pretreatment in drying. The effective diffusion rate of moisture also shows conducive results. On further studying this mode of pretreatment, industrial utilization of UV may be used as a non-thermal, non-chemical, cleaner alternative for pretreatment for drying.

3.Further scope of Research

To further correlate and understand the changes of microstructure and drying rate due to UV pretreatment, use of SEM may be considered. This would help understand the changes in structure, which in turn can help in understanding the effect of various pretreatments at various exposure duration, on the drying kinetics.

Moreover, UV as a pretreatment for other conventional drying methods such as open drying, shade drying may also be studied. This would provide valuable data for consideration for use of UV pretreatment for conventional drying process and also help establish correlation of UV pretreatment with various drying processes.

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