PEOPLE'S DEMOCRATIC REPUBLIC OF ALGERIA

MINISTRY OF HIGHER EDUCATION AND SCIENTIFIC RESEARCH

University of Mohamed El-Bachir El-Ibrahimi – Bordj Bou Arreridj

Faculty of Science and Technology

Departement of electronics

Discuss the graduation thesis in order to obtain the degree of MASTER

Fields: electronics of embedded systems

Subject:

Design and development of an automatic electric dehydrator for food products

Presented by: **AMZALI Mohamed Nadir**

Jury members:

First name & Last name	Grade	Quality	Establishment
Dr. Abdelhalim Brahimi	MAB	President of Jury	BBA University
Dr. Idir Nezzari	MAB	Examiner	BBA University
Dr. Raouf Zerrougui	MAB	Supervisor	BBA University
Dr. Abdelallah Bengdoudj	MCB	Representative of the Incubator	BBA University
Dr. Ammar Noui	MCA	INVITED	BBA University
Dr. Abderrahim Yousfi	MCB	INVITED	BBA University

2023/2024

Thanks

*First of all, we would like to thank **ALLAH**, who has empowered me from the first year of primary school to this day of graduation and asked him to bring me more to continue.*

*The most distinguished thanks go to my supervisor **Dr. ZERROUGUI***

who enabled me to carry out this project and supported me with his advice and guidance.

I would also like to take this opportunity to thank our teachers who contributed to our training, and all the staff at the Bordj Bou Arreridj University

I would like to thank the members of the jury who agreed to do me the

honor of judging my work.

Dedication

I dedicate this modest work to:

To my dear mother.

To my dear father.

To my brothers and sisters.

To all my family.

To all my friends.

To all my dearest colleague.

To everyone helps me to do this work.

For everyone who knows ME.

TABLE OF CONTENTS

TABLE OF CONTENTS

Abstract

This project focuses on the design and development of an energy-efficient food dehydrator tailored to the needs of small-scale producers and households. The dehydrator is designed to address key challenges such as high energy consumption, uneven drying, and lack of user adaptability in conventional models. By integrating insulation, enhancing airflow, and a user-friendly manual control system for temperature and drying time, the dehydrator achieves a 50% reduction in energy usage while delivering consistent drying performance. Rigorous testing has validated the system's efficiency, usability, and ability to process various food products, including fruits, vegetables, and herbs. This locally manufactured solution offers a sustainable and cost-effective approach to food preservation, contributing to food security and environmental conservation goals.
Keywords: Food dehydration, energy efficiency, user-friendly design, airflow optimization, sustainable food preservation.

Résumé

Ce projet porte sur la conception et le développement d'un Déshydrateur alimentaire économe en énergie, adapté aux besoins des petits producteurs et des ménages. Conçu pour répondre aux défis majeurs tels que la consommation énergétique élevée, le séchage non uniforme et le manque d'adaptabilité des modèles conventionnels, le Déshydrateur intègre une isolation, une circulation d'air amélioré et un système de contrôle manuel convivial pour la température et le temps de séchage. Il permet une réduction de 50 % de la consommation d'énergie tout en garantissant des performances de séchage constantes. Des tests rigoureux ont validé son efficacité, sa facilité d'utilisation et sa capacité à traiter une variété de produits alimentaires tels que les fruits, les légumes et les herbes. Cette solution, fabricable localement, offre une approche durable et rentable pour la conservation des aliments, contribuant à la sécurité alimentaire et à la protection de l'environnement.

Mots-clés : Déshydratation alimentaire, efficacité énergétique, conception conviviale, optimisation du flux d'air, conservation alimentaire durable.

الملخص

يركز هذا المشروع على تصميم وتطوير مجفف طعام موفر للطاقة ومصمم خصيصًا لتلبية احتياجات المنتجين الصغار والمنازل. يهدف المجفف إلى معالجة التحديات الرئيسية مثل الاستهلاك العالي للطاقة والجفاف غير المتساوي وعدم القدرة على التكيف في النماذج التقليدية. من خلال دمج عزل، وتدفق هواء محسن، ونظام تحكم يدوي سهل الاستخدام لضبط درجة الحرارة ووقت التجفيف، يحقق المجفف تقريباً نسبة 50٪ اقل في استهلاك الطاقة مع ضمان أداء تجفيف متسق. أثبتت الاختبارات الصارمة كفاءة النظام وسهولة استخدامه وقدرته على معالجة مجموعة متنوعة من المنتجات الغذائية مثل الفواكه والخضروات والأعشاب. توفر هذه الحلول التي يمكن تصنيعها محليًا نهجًا مستدامًا وفعالاً من حيث التكلفة لحفظ الأطعمة، مما يساهم في تحقيق الأمن الغذائي والحفاظ على البيئة.

الكلمات المفتاحية: تجفيف الطعام، كفاءة الطاقة، تصميم سهل الاستخدام، تحسين تدفق الهواء، حفظ الأغذية المستدام.

LISTE OF FIGURES

LISTE OF TABLES

ACRONYMS

DC	**D**irect **C**urrent
IDE	**I**ntegrated **D**evelopment **E**nvironment
PWM	**P**ulse **W**idth **M**odulation
SPI	**S**erial **P**eripheral **I**nterface
USB	**U**niversal **S**erial **B**us
AC	Alternating Current
RTC	**R**eal **T**ime **C**lock
SPI	**Serial Peripheral Interface**
ICSP	**In-Circuit Serial Programming**
EEPROM	**Electrically Erasable Programmable Read-Only Memory**

GENERAL INTRODUCTION

Food preservation has always been a fundamental necessity for humanity, enabling the storage and consumption of food long after its harvest. In modern times, the need for effective preservation methods has become even more critical due to global challenges such as population growth, food insecurity, and the increasing demand for sustainable solutions to reduce food waste. Among various preservation techniques, food dehydration stands out as one of the oldest and most reliable methods. By removing moisture from food, dehydration inhibits microbial growth and extends the shelf life of perishable items, offering a practical solution for reducing waste and improving food availability.

Despite its advantages, traditional food dehydrators face several challenges, including high energy consumption, uneven drying, and limited adaptability for different food types. These shortcomings not only increase operational costs but also restrict the accessibility of such systems for small-scale producers and households. Addressing these issues is essential for developing sustainable and cost-effective food preservation technologies, particularly in regions like Algeria, where seasonal agricultural abundance often leads to significant post-harvest losses.

This project focuses on the design and development of an energy-efficient food dehydrator tailored to the needs of small-scale users. The dehydrator incorporates insulation to minimize heat loss, an optimized airflow system to ensure uniform drying, and a manual control interface for temperature and timer adjustments. With a targeted energy reduction of up to 50%, the system is designed to significantly lower operational costs while maintaining high drying performance. Additionally, the use of locally available materials and components supports sustainable production practices and affordability, making the dehydrator an accessible solution for diverse user groups.

The scope of this work extends beyond the technical design of the dehydrator. It includes rigorous performance testing to validate its efficiency, durability, and usability. By demonstrating consistent drying results across various food products, including fruits, vegetables, and herbs, this project contributes to enhancing food security and reducing waste at both household and commercial levels. Furthermore, the project aligns with global sustainability efforts by promoting energy conservation and reducing the environmental impact of food preservation technologies.

This introduction sets the stage for the detailed exploration of the project in the following chapters, encompassing the state-of-the-art research, design, development, testing, and market viability of the food dehydrator. It highlights the project's significance in addressing pressing food preservation challenges while paving the way for innovation and sustainability in the field

CHAPTER 1

THE STATE OF THE ART ABOUT FOOD DEHYDRATION

1 CHAPTER 1: THE STATE OF THE ART ABOUT FOOD DEHYDRATION

1.1 INTRODUCTION

The method of removing moisture from food has been used for a long time, tracing back to ancient times and becoming popular again during world wars when there was a high demand for food supply, The dehydration process has been applied from early periods, and nowadays, it is used in all the industry branches [1], This resurgence was known as 'Dehydrated for Defense'. Advances in mass technology and new food processing methods have led to an increase in the consumption of snacks, food ingredients, and convenience foods in modern times. Consumers are now seeking convenient, natural, nutritionally dense, ready-to-eat, and single-serve food products that offer quick and enjoyable taste and texture, eliminating the need for home preparation. This growing demand has been fueled by the adoption of new food processing methods.

Currently, one of the trends in food is dehydrated vegetable consumption and along similar lines the demand for dehydrated meat and fish. Research and commercial interest in food dehydration have grown during the last three decades. In terms of economics, dehydration is often used as an additional step in the manufacturing of packaged ready-to-eat foods. Dehydration primarily profits from the consumer's requirement for naturally derived food items with a prolonged shelf life and ease of usage. Advantages of food dehydration as an emerging field of interest include technological orientation, energy-conscious orientation, environmental awareness, and health orientation. The aim of the study primarily includes an extensive and in-depth study and critical literature understanding of present-day food dehydration and postulates a road plan and scope for future investigations on the said subject. For the large number of public and organizational entities, this study may have implications ranging from agriculture to public health and civil administration.

1.2 HISTORICAL DEVELOPMENT OF FOOD DEHYDRATION

Traditional food dehydration processes by sun and wind or convection heating in various cultures. Primitive methods have been used to dry food products for thousands of years. This type of food drying is achieved using the heat from the sun, convection heating by wind, or other modes of air drying (courtyards, exposed balconies, roof areas, hanging racks). Such methods have been in routine use in the traditional food industry of various countries.

Several reviews summarize the historical development and technical advancement achieved in the area of conventional and advanced food dehydration techniques. The study of products in an oven dry system has been investigated. Different scientific and patent publications on pulse electroporation have been reviewed. Microwave heating has been investigated. Cone drying theory has been reviewed. The convective air-drying characteristics of potatoes have been studied. Available information suggests that innumerable research studies have been carried out on improving food dehydration technology by utilizing various energy sources. However, no one has attempted to conduct a comprehensive review of this evolutionary process.

Dehydrating food helps prevent bacterial growth that causes changes in chemicals and the occurrence of spoilage and the in food by reducing the moisture content of dietary items [2], he thermal dehydration of food is essential to prevent the growth of bacteria, mold, and yeast, as well as autolysis and protozoan development. Advanced methods of food dehydration were also developed to produce products of good quality. From these related arguments, it can be said that food conservation techniques were developed and improved based on human requirements to satisfy the needs of the specific time of human existence, during World War 1, the United States shipped about 4500 tons of dehydrated vegetables, Potatoes, cabbage, spinach, turnips, carrots, celery, sweet corn, green beans, and soup mixtures were among the products processed in the United States [2]. The need for food preservation entirely depends on the habitat of human existence, with changes in lifestyle, environment, and personal preferences of societies, civilizations, and finally human beings.

1.3 PRINCIPLES AND MECHANISMS OF FOOD DEHYDRATION

Food dehydration is a unitary operation that removes moisture from fresh food materials by vaporizing it in hot air to create semi-finished products. Moisture removal has clear advantages, such as reducing the total water content, preventing water-related diseases, allowing the product to be stored for a long time, and reducing transportation costs. The dehydration process depends on various factors related to the thermodynamics and kinetics of the phenomena associated with moisture and the product composition of the food. The utilization of thermodynamics and kinetics mechanisms experienced by the food product undergoing a drying operation showcases the efficiency of the operation to remove the needed moisture. This removes the complexity and ambiguity that characterize the incomplete knowledge of the suitable control mechanism in the drying process of a food product [18].

A reduction in water content in the raw product leads to a decrease in water activity, which is responsible for food spoilage. Some climate and geographical conditions of the areas visited make it easier to access products such as fresh fruits and vegetables during the production seasons. Locally grown fruits and vegetables are now available nearly all year round. Many organizations today are seeking to improve the quality of these foods, hence the interest in food dehydration, it is expected that the new generation of dryers and drying technologies promote more sustainable development with higher thermal and energy efficiency, lower operation costs and improve product quality [3]. There are currently a number of strategies used to reduce the moisture content in these foods. The most effective methods use heat, with the heat application process ranging from basic to highly technical and specialized. With specific technology, knowledge, and equipment, hydrated foods can be steam-removed, heat-retained, and protected from further contamination or damage. Here in, the main application of heat is incorporated using hot air, The mechanism of water removal by drying involves two simultaneous processes, namely transfer of heat for the evaporation of water to the food and transport of the water vapors formed away from the food [4], The warmth of the drying mechanism toward the target product is directed by the involvement of the designed strategic climate, airflow, and temperature that would be suitable for the product. It is not a one-way design that works for every sample type under a single controlling principle. Many variables can be adapted to ensure the possibility of producing a high-quality end product using a set of methods.

1.4 ADVANTAGES AND DISADVANTAGES OF FOOD DEHYDRATION

2-1 ADVANTAGES AND DISADVANTAGES OF FOOD DEHYDRATION [17]

Advantages of Food Dehydration	Disadvantages of Food Dehydration
Extended Shelf Life: Dehydration significantly increases the shelf life of food by reducing moisture, which prevents microbial growth.	**Nutrient Loss**: Some vitamins (e.g., Vitamin C) and minerals may degrade during the dehydration process, especially at high temperatures.
Space and Weight Reduction: Dehydrated foods are lighter and more compact, making them easier to store and transport.	**Texture Changes**: Dehydrated foods may lose their original texture, becoming brittle or tough. Rehydration may not fully restore the texture.
Convenience: Dehydrated foods are easy to handle, store, and prepare, requiring minimal preparation (e.g., just add water).	**Flavor Changes**: Dehydration can sometimes alter the flavor of foods, and rehydrated products may not taste as fresh as their non-dehydrated counterparts.
Retention of Nutritional Value: Proper dehydration methods retain a high percentage of the food's nutrients, especially if low temperatures and gentle drying methods are used.	**Energy Consumption**: Some dehydration methods, like freeze drying or microwave drying, can be energy-intensive, leading to higher operational costs.
Preservation of Natural Colors: Many drying methods preserve the natural color of food, making it more visually appealing.	**Initial Setup Costs**: Advanced dehydration technologies (e.g., freeze drying) can have high upfront costs for equipment and infrastructure.
Reduction of Food Waste: Dehydrating surplus or seasonal produce reduces food waste by prolonging shelf life and making it available year-round.	**Not Suitable for All Foods**: Some foods, especially those high in fats (e.g., avocado), do not dehydrate well and can become rancid over time.
Healthier Snack Option: Dehydrated foods retain much of their nutritional content, making them a healthy snack choice compared to processed snacks with preservatives.	**Rehydration Challenges**: Some products may not rehydrate well, affecting the texture and flavor when reintroduced to water.
Cost-Effective for Bulk Production: Dehydrating food in large quantities can be cost-	**Potential for Over-Drying**: If not carefully monitored, dehydration can over-dry food, causing loss of flavor, texture, and nutrients.

Advantages of Food Dehydration	Disadvantages of Food Dehydration
effective, especially in industrial or commercial applications.	

1.5 TRADITIONAL METHODS OF FOOD DEHYDRATION

Dehydration as a means of preserving food has been practiced historically for longer than can be documented. Whenever factors such as low energy cost, limited access to fresh foodstuffs, or conservationist motives have come into play, dehydration has proven to be a suitable alternative to freezing or canning. Such traditional methods have been in continual practice for hundreds of years, and for some techniques, for thousands of years. The first is sun drying, which is still universally practiced when required by circumstances. However, various degrees of refinement to increase the speed and evenness of drying can often be seen in local practices, some of which include forced air circulation, results of which can vary from no differences being found to examples of faster drying in forced air systems.

Traditional methods of preserving perishable vegetables include sun dehydration, which involves exposing the vegetables directly to the sun to absorb its radiation. Grapes, prunes, and figs, among other dried fruits, have been preserved using this method to an extensive degree in recent years [2].

Two other traditional forms of air dehydration are commonly still practiced, these being simple air-drying, such as might occur on screens or well-aerated attics or lofts. The other is smoking over wood fires, with our recent example of the popularity of Welsh gammon as a gourmet product. Two world-famous examples of solar-dried products are sun-dried tomatoes and Turkish sun-dried apricots, which are a casual and healthful snack food. Dried fruits tend to be much firmer than their reconstituted equivalents, and this explains some but not all of their appeal [17], as they may be eaten in situations or cultures where the high-water content of fresh fruits is not desirable. While fresh fruit is sometimes overlaid with thick syrups to preserve it in some cultures as preserved fruits, pieces of fruit are more universally preserved than whole fruits. Jams, for instance, are generally made from exposed fruit that has lost some of its water by dehydration and consequently now provides a desirable substrate for preserving in heavy sugar syrup. In addition, the less fragile the fruit piece, the easier the dehydration process, as fragile pieces of fruit tend to shrink and shrivel excessively, and the appearance of the final drying product makes it unsuitable as a premium product. For example, store or cigar quality tobacco is always air-cured, and the same drying technique is also used for curing some other leaves, such as tea.

1.6 Modern Technologies in Food Dehydration

The modern methods of food dehydration have flourished greatly over the years. They have been designed using state-of-the-art technology to maximize nutrient retention and sensory properties of dehydrated foods. These methods are categorized as follows:

1.6.1 Freeze Drying

Lyophilization, more commonly known as freeze drying, is often mistakenly thought of as simply a drying process, yet it is actually a sublimation process. Water is driven from food products by sublimation without going through a liquid phase. This can only occur given that it is possible to directly move from the solid to the vapor state under a vacuum. In general, the production cycle in freeze drying or lyophilization is composed of three phases: freezing, primary drying (sublimation), and secondary drying, often in that order but not necessarily. Freeze-drying has certain advantages. It retains the structure of food, and the shelf life can be considerably greater than air-dried products. Freeze-dried materials also have low density and are very light. Freeze-dried products are used largely by the pharmaceutical industry but have a small but significant market in the food industry. They are used as camping or military rations and are also used by astronauts. In terms of foods, freeze-drying is currently being utilized mainly for vegetables, fruits, berries, seafood, and some dairy products. However, freeze-drying has a relatively high energy requirement and, consequently, is more expensive than air-drying as well as spray-drying [2].

Figure 1 Freeze Drying machine

In comparison with other dehydration methods, freeze-dried products have the best appearance, color, texture, and other sensory characteristics. They also possess a highly compartmentalized structure and reconstitute with a minimum of swelling compared with air-dried and vacuum-dried products. The future development of lyophilization mainly lies in freeze-drying removal efficiency for reduced drying time and an improvement of inactivation methods. Many research papers in lyophilization conduct closed-loop control, and future lyophilization will be controlled for relevant variables, including primary and secondary shelf temperature. The optimization continued research emerged, such as production cost research, such as water production rate on the surface of the spherical meat shape or chicken breast substrate, lump meat. Vacuum foam drying technology is one of the potential alternative methods to replace freeze-drying. It can be competitive with freeze-dried products in lower production costs and certain product quality. Future food vacuum foam drying research needs to reduce energy utilization and speed up the drying process without damaging the product quality, such as the aroma and volatile components.

1.6.2 Vacuum Drying

Drying at low pressure is the operational principle of vacuum drying, whose most important advantage is that the boiling point of water is lowered within the food as the pressure around it is reduced. In combination, this allows water to be removed from foods at lower temperatures [2]. Vacuum drying is thus a gentle drying technique that minimizes heat damage and shrinkage of the dehydrated food product while lessening the evaporation time as well. Monolayer water may be present in the dehydrated material, which can be especially useful in the prevention of caking in dried liquid and pouring powders. As a result of the above positive qualities, vacuum drying technology is important in functional foods, pharmaceuticals, herbs, detergents, and so forth.

Figure 2 Vacuum Drying machine

Although vacuum drying has these and other advantageous characteristics, the drying process remains ineffective for drying perishable products, such as fruits and vegetables, at ambient temperature; thus, such products typically require pretreatment prior to vacuum drying in order to inactivate their enzymes, reduce the value of their water activity, and reduce their heat capacity and thermal conductivity. Concurrently, vacuum drying is more expensive due to the elevated investment and running costs associated with vacuum systems, which sometimes require the use of additional labor and the consumption of auxiliary materials. In summary, vacuum drying is not a drying method that is favorable for every type of condition.

Although vacuum drying technology is not completely disease-free, it helps retain substantial amounts of important water-soluble vitamins. It protects food flavors better in many cases than other drying techniques. Also, non-destructive drying at high temperatures potentially preserves almost all of the food's moisture content. The need for vacuum drying in situations where sensitivity to heat, air, or processed materials applies is a compelling catalyst for the additional promotion of such technology.

1.6.3 Spray Drying

Spray drying is one of the most important and oldest dehydration processes. In this technique, liquid feed is atomized into hot gas, which causes rapid evaporation of the moisture, leading to the formation of dry powders. The spray drying process is very effective for moisture removal, which is critical for food preservation. This widely used technology has applications in nearly all food industries to produce powdered products [2]. In addition, spray drying can enhance the shelf stability of such products. An advantage of spray drying over other drying techniques is that the particles are mostly uniform in size, shape, and composition. Despite its advantages, spray drying can create oxidized and heat-sensitive flavors, thereby diminishing the overall flavor, taste, and color of the product. Several technologies are being used to reduce the adverse effects of this process. Numerous advancements and studies need to be performed to improve spray drying in order to keep pace with the needs of the business and technology.

Figure 3 Spray Drying machine

The spray-drying market is continuously evolving with multiple improvements in the process and system in terms of atomization, heat, mass transfer, powder characteristics, and energy use. There are four dominant sections and five smaller considerations when it comes to optimizing a spray-drying process in technology marketing. Current crop producers and agribusinesses are developing more freeze-dried and spray-dried health and functional food ingredients, which are less dependent on restrictive markets. It is predicted that the demand for spray-dried functional beer ingredients will double in North America in the foreseeable future.

1.6.4 Microwave Drying

Among non-conventional drying techniques, microwaves can be considered a progressive approach. The application of microwave results in bulk heating and excitation of either the electric or magnetic dipole of water. However, the absorption of microwave, which is typically done at the center of the material, may vary with changes in moisture content, salt, sugar, and fat in food, and thus over the volume and time. Due to rapid internal moisture removal [2], microwave drying techniques are well known for their rapid heating and drying, and it is estimated that the energy requirements are only compared to other drying methods. In addition, microwaves can be particularly useful for the rapid drying of heat-sensitive products while minimizing thermal degradation during the drying process.

Figure 4 Microwave Drying machine

Apart from the many technical advantages, some limitations have prevented a wider application of microwave drying in the food industry, particularly imperfections in the acceptability of the product related to the texture of the solid substrate. Many workers report non-uniform drying, some of whom suggested possible remedies: agitating sample material during drying, pre-heating the product for several hours, or moisturizing the dried product to even out the final moisture content. Despite these challenges, microwaves are currently used only for drying fruits and vegetables and pre-cooked products that contain low moisture content **[9]**. Industrial drying processes have taken little advantage of microwave technology, mainly because of a lack of research support and reliable equipment. In the past few years, there has been renewed interest in this subject, as evidenced by recent research contributions. In practical applications, microwave energy has many advantages, including high heating rates, relatively short processing times, lower final moisture content of dehydrated materials, retention of natural flavor properties, and color of the food materials. These merits can be very useful in large-scale drying and dehydration applications.

Over recent years, the use of microwave drying has attracted considerable attention. Besides the conventional microwave technology, several reports have noted the development of new microwave cavities or the development of new processing techniques to overcome some limitations of the use of microwaves in drying. Up-to-date work on microwave techniques is systematically presented. The outcome shows that drying kinetics and quality of food products can be influenced significantly by different microwave hybrid configurations, with significant potential to control fungal growth on peanuts using microwave technology, adaptation of a microwave prototype to test the dielectric properties of agricultural materials, and innovative microwave processing for special food.

1.6.5 Tray drying

It has a simple design and can dry a lot of stuff. The first hot air dehydrator was invented in 1795 and used to dry fruit and vegetables, such as raisins and prunes. The proper operation of the tray dryer depends on an even distribution of airflow over the trays. Colak and Hepbasli developed a green olive model in 2007. The first energy efficiency study of dehydrators was conducted in 1921 by Christie and Cruss. At the time, heated forced-air dehydrators were used to dry prunes instead of sun use. The prime problem with the tray dryer is irregular drying caused by inadequate airflow dispersion in the drying chamber. The efficiency of a tray dryer system can be increased, and drying nonuniformity can be minimized. Due to the systems' low operating costs, many dryer structures have been created using solar energy [2].

1.7 QUALITY ASPECTS IN DEHYDRATED FOODS

The quality of a food material is an important parameter in measuring the acceptability of a product. The quality of food is affected by three factors: the composition and availability of key nutrients, the structure of the food material, and the sensation felt by the consumer, all of which can change during dehydration. After the drying process, the moisture content of various food items is reduced significantly. This constant moisture content results in lesser water activity. The purpose of food dehydration is to prolong the shelf life of the food. Dehydration has been one of the most popular and ancient methods of preserving food for a long time. Depending on the preservation process, the effect on food will vary. Retention of nutrients at the same level may reduce the level, or it might be increased depending on the process **[10]**.

Three significant quality aspects are considered in the dehydration process: nutritional quality, which includes vitamins and minerals; texture quality, which includes a long-lasting, non-hard mouthfeel and complete elimination of sand or synthetic sensations; and physical quality, which includes color. The maintenance of nutritional quality during processing is primarily influenced by the drying methods and a little by the pre-treatments given to the food material prior to drying. Texture quality is affected by the moisture removal rate and the final moisture level of the sample, which is directly influenced by the drying methods employed. Physical quality is maintained by housekeeping during the drying process, including the removal of fines, abrasion, breakage, and undegrading. Flavor quality is primarily maintained by low-temperature drying or mild drying conditions. Efficient and correct drying procedures control it. Industry quality requirements and consumer preferences are the driving forces for selecting appropriate and efficient dehydration methods [5].

1.7.1 Nutritional Retention

Dehydrated foods are known for their long shelf life, an attribute due to low moisture content. This preservation method is also preferable, given that dehydration can preserve sensory characteristics such as color, aroma, and nutrients. Since only water is removed, vitamins and minerals remain preserved. The nutrition of freshly dried food is often taken into account when comparing food quality attributes. Nutritional retention is the degree to which the essential nutritional components are confined or protected during the processing of different food commodities [5]. Given these benefits, numerous researchers have investigated the influence of drying techniques on food. One parameter studied was the accumulation of bioactive essentials in dehydrated fruits. The studies also highlighted the influence of drying techniques on energy consumption and nutrition. Of the studies done, only 60% are on thermal drying techniques, with the rest dedicated to non-thermal drying techniques.

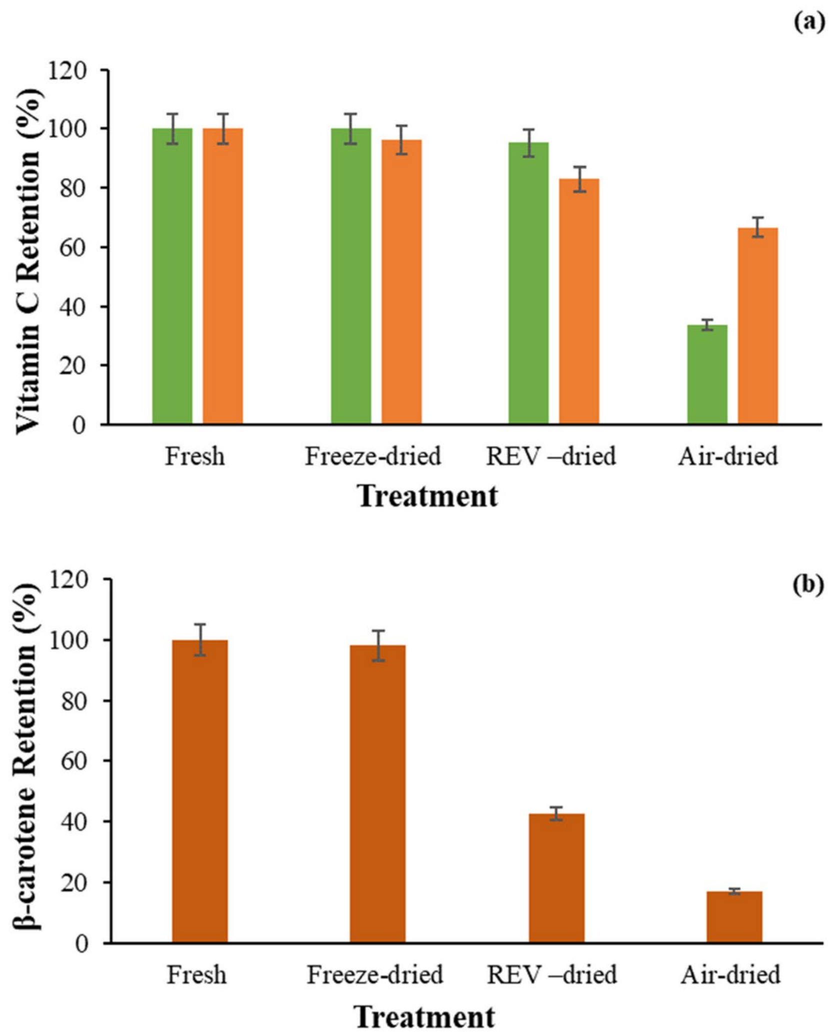

Figure 5 (a) Retention of Vitamin C in broccoli (G) and oranges (O) (b) Retention of carotene in % [5].

Non-thermal drying techniques were deemed general mainly because their technology was applicable or the process of dehydration was widely and commercially used. From the review, the dried foods processed with the critically investigated techniques were found to have an average minimum nutritional choice from the following parameters: antioxidant, vitamin, and sugar. Higher nutritional quality was also attributed to foods dried through various non-thermal drying techniques. The collateral of the retained nutrients increased with decreasing temperature and extending drying time for all food products. In both dehydro-frozen and ultrasound drying methods, only one research study on the qualities of the product showed collateral in nutritional quality. Within this subsection, recommendations were also given on how the studies would have the same nutritional quality. It was discovered that improved nutritional retention on dehydrated food products can boost consumer purchasing but may bring further health improvements. Research on the influence of drying techniques on food processing has shown that thermal techniques reduce the sensory acceptability of fruit quality. Whenever safe water content is set, more nutrients are retained, and better taste control can be produced in the final product. However, the influence of the drying technique on food depends on the type of food matrix, type of food, and process temperature.

1.7.2 Texture Preservation

Texture retention is another important criterion for dehydrated foods, as it is personalized and linked to consumer acceptance. Dehydration-induced changes in the texture of horticultural products are characterized by changes in the water binder state in the tissues, which result from moisture loss, as well as the modification of the cell wall and cell membrane structures, altering the macrostructure of food. The original food texture can be modified to a rubbery or glassy texture according to drying conditions. The glass transition temperature determines the boundary condition for physical and biological changes during drying. When the food temperature is less than Tg, the water in the cells is frozen. It becomes solid, which makes a transition from volume shrinkage at the falling rate period to volume vibration at the constant rate period. While the food temperature is greater than Tg, water in the cells becomes supercooled and eventually vaporizes by desorption. The volatility of the thaw period transferred to Tg of VRDP is going to be a good quality indicator [5].

The texture change can be minimized by using a pre-treatment and occurring slowly in the high-humidity drying process. The dried product requires air storage or is rehydrated back to its original state (if required) with good reconstitution characteristics. Most consumers judge the quality of the dehydrated product based on appearance, followed by flavor and texture. The industry is trying to improve the texture of dehydrated products. Texture determination is developed regarding dehydration, provided that texture must be evaluated in connection with the various dehydration methods and product confirmation.

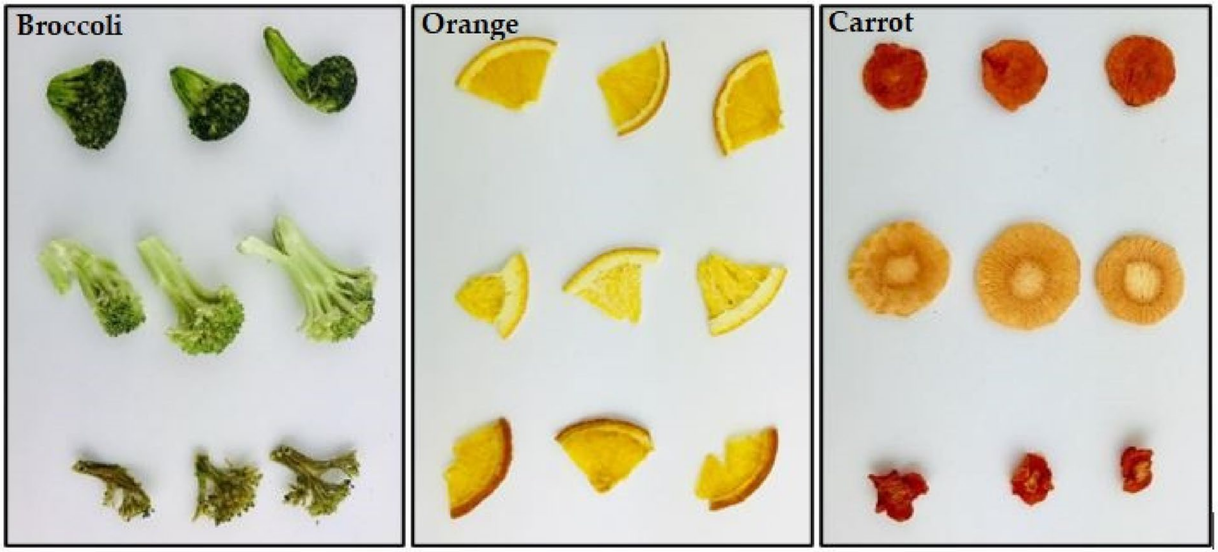

Figure 6 Broccoli, orange, and carrot immediately after drying [5].

1.7.3 Color Retention

Color is an important quality parameter for dehydrated foods. External appearance influences the consumer's first perception of product quality and purchasing decisions. As is the case in other food processes, dehydration techniques can affect both pigmentation and the appearance of dried products. Many factors, such as drying conditions, bioactive compounds, and antioxidant and antinutrient content in raw materials, may indirectly affect the pigmentation and visual aspects of dried foods. For an enzymatic mechanism, the drying temperature should be carefully controlled to obtain a final powdered product of more acceptable stability with respect to pigmentation. In particular, the time at which the time-temperature combination applied during dehydration changes from one lethal value to another value that leads to a decrease in residual enzyme activity to commercially acceptable levels indicate the time-temperature equivalence of the total blanching process. Using this method [5], a more precise study of an equilibrium condition between desirable activity inhibition and a reduction in the nutritional and bioactive properties in dried vegetable materials with or without soaking and pre-blanch treatments was performed. For color retention, the drying temperature is crucial, and it varies from one commodity to another.

Figure 7 lemon and orange color change after drying

Color is a collective term because the measurement of the color of food involves total appearance attributes of anything affecting the appearance attributes of food materials [5], primarily hue and lightness. Color is especially important for dehydrated food products, as these products must be satisfactory to consumers for their appearance, flavor, and texture. Color is the first quality attribute that determines the acceptability or rejection of a product. The development of technology to improve color characteristic quality is important, as this will aid in generating superior products with improved consistency. This will allow marketers to address the public's desire for plump and juicy fruits in new markets that require enhancement in product appearance. Thus, producers can move products from the bottom of the market grouping to products that command higher prices. To this end, it was investigated whether urea impregnation could mitigate the browning effect by increasing the lightness of dried onions. The application of the optical property of the product suggests that a nonenzymatic mechanism is responsible for the browning occurring in dried onions, L values from extrinsically blanched and non-blanched products, and unimproved fresh control.

1.8 APPLICATIONS OF DEHYDRATED FOODS

Dehydrated products have been important in the food industry since its inception. They served several purposes at various times: processing, packaging, handling, preserving, and serving, which were all optimized into convenient packages. A variety of forms of convenience foods, such as instant coffee, dry seasoning, and breakfast cereals, entered the marketplace in the early part of the 20th century. Fast food and convenience stores emerged, as did frozen foods, dried soups, cake mixes, and other prepared foods, where consumers were willing to pay for personal services and imported labor in any sized commodity packages. High-quality products are the super-premium line flour products and some other electronic line forms, including gluten-free products. At the same time, Ultima could be used in manufacturing and other food applications [11].

Another application of dehydration is in the emergency and military rations field, where dehydrated food is used to provide lots of calories in a low-volume and low-weight package that does not require refrigeration. Fresh fruits and vegetables await shipment to fresh food from any corner of the globe at any time. Still, dehydrated foods are a practical alternative whenever fresh or refrigerated food must be packed. Spacecraft, with their limited space, can carry out long-term missions that require lightweight foods that are highly energy-dense. The compactness and lightness of dehydrated foods make them particularly attractive to companies engaged in mail order and export of gifts and gourmet foods to the rest of the world. In response to consumers' desires for 'fresh' foods, another major market for dehydrated foods in recent years has been the retail trade, as easy-to-rehydrate raisins and other small dehydrated fruits have appeared as treats for children. In addition to the uses above, a wide variety of other applications for dehydrated products are slowly being explored and developed for specialized markets.

1.8.1 Food Industry

In the food industry, dehydrated products have become increasingly appealing due to their convenience for consumers and long shelf life, contributing to vast time and energy savings for modern households. In many countries, the production of dried foods is expected to yield remarkable dividends for future markets, and consumer trends are largely contributing to food consumption. In addition to household consumption, dried foods have found applications in several industrial markets, particularly in the preparation of soups, ready-to-eat meals, flavorings, extruded snacks, and many other foods. One of the greatest benefits of using dried foods as ingredients in food preparation is that the end products can be stored for an extended period with the same flavor and nutritional value as freshly made products. Dehydration of food eliminates a major portion of the water content from the product and reduces the weight and volume significantly, resulting in potential savings on logistics and storage. Other applications, such as the use of dried vegetables in the preparation of instant soups or ready-to-eat meals, contribute to the demand for dehydrated goods. The increase in frozen storage capacity has led to the development of several fruits, vegetables, ready-to-eat meals, sauces, and soups in the Western food sector. The quality consistency of dried foods, coupled with a long shelf life, has paved the way for their utilization in these sectors. The industry is investing heavily in research and development for the introduction of semi- or non-perishable foods, which would help offset the long-haul costs of stale and uninteresting products. This was heavily pronounced in various unofficial debates with industry representatives. Moreover, changing consumer preferences and eating habits have directly influenced the increasing demand for dried food in retail markets.

Currently, numerous dehydration technologies are used in the food industry for the production of dried foods, which also corroborates the development of this sector. This is an indicative example of increasing the variety of extracts from the same raw material, which is of benefit to neither producers nor consumers. In contrast, dried food is available that meets specific quality and health-related criteria. However, the use of sophisticated food technologies is the first step in niche growth for market traders. Advances in the science of food, such as the incorporation of electrical and electronic engineering, mechanical engineering, and artificial intelligence, have made it possible to develop reliable software to accompany equipment for the development of mildly produced dried foods that technically meet the quality and safety requirements of the delivered goods.

1.8.2 Emergency and Military Rations

Staples of any disaster, emergency, or military rations are dehydrated and freeze-dried meat and vegetable products. The armed forces have been using rations specifically designed to be light and portable and to meet the daily intake of basic nutrients per 24-hour ration package in full for over 60 years. Not only do the foods have to be nonperishable, but they also have to have a long shelf life. Advances in research and technology have allowed food products to evolve quickly in terms of not only ingredients and taste but also texture and influential physical factors as well. Characteristics related to organoleptic properties (flavor, appearance, and texture) have been particularly and successfully addressed.

Logistical and technical problems associated with sourcing, storing, and distributing large quantities of fresh products to an affected population have led to increased use of alternative rations in unrelenting crisis settings. In some cases, dehydrated rations play a valuable role in meeting the food and associated needs of the affected population. In situations where large-scale catering is the established mode for providing food assistance, local or region-specific foods that the affected populations are accustomed to consuming have recently started to become included as part of the technology. As a result of such advancements, and with the emphasis placed by armed forces on nutrition and palatability, recent initiatives include providing not only regular and full meals ready to eat but also food acceptable to those of religious and social cultures requiring special diets which, given the advances in dehydration techniques and the availability of large quantities of protein, are being expressed in the form of dehydrated meals.

For both Canada and the United Kingdom, ration design involved considerable field trials and evaluations to guarantee the optimum degree of acceptability and nutritional intake. Research is currently being conducted to develop rations further. Topics include the development of food products for use by the armed forces, which will explore various methods of dehydration, as well as processing and packaging, with the objective of achieving new food products based on the foods available from the commercial market, with improved quality and nutritional supplements developed for soldiers. The influence of different drying techniques on food quality and environmental scanning for recent scientific and commercial advances in food products will be explored in seminars on shelf-stable foods. Trends and uses of convenience foods will also be discussed. Research interests include the recovery of energy and protein from underutilized agricultural commodities for use as part of military rations, dehydration and its effects on nutrient content and quality of food products, cereal-lipid interactions, and the development of nutrition bars.

1.8.3 Space Travel

Astronauts at the International Space Station (ISS) are provided with pre-packaged, dehydrated foods to prolong the shelf life and lower the cost of the food supply for long-duration space missions [15] A. D. Garcia, V. Leyva, J. Bocková, R. L. Pepino, and C. Meinert, "Resolution and quantification of carbohydrates by enantioselective comprehensive two-dimensional gas chromatography," Talanta, vol. 271, p. 125728, 2024.

. To date, space agencies from around the world have contributed considerable resources towards the optimization of dehydration methods, recipe development, and quality design of individual food items, the primary objective, beyond nutrition, being overall acceptance. It is necessary to supplement the daily energy and essential nutrients needed to maintain health and productivity, which are lost or consumed during extravehicular activities (EVAs) with nutritious food products. Early missions to space took foods that were similar to conventional diets; however, these have poor shelf life, are bulky and wasteful, and have prohibitive mass. Foods such as these are not only tricky to store during long-duration space missions but also result in the production of waste, and the containment of waste is highly problematic [15].

The provision of a variety of travel food is important, as an adequate store of such items is not only required for fuel but also for a psychological boost to maintain good crew morale, as complete physiological and psychological well-being in astronauts is critical. Mission planners have identified the need for increasingly cost-effective, multi-functional, and reusable sources of food that will last. Given the extreme cost and the weight efficiency of transporting food, from an engineering perspective, nutritious food is key to surviving the space environment and to the capacity to work and productivity. However, the need for lightweight and low volume is therefore secondary to the ability of food to sustain human physiology, psychology, and overall well-being. There is interest in developing processing technologies that maximize the nutritional value and palatability of the food. Market research has shown that consumer acceptance and taste of specific food items are key factors that impact consumer satisfaction with the food overall. The interest in and popularity of 'space food' leads to an ever-rotating debate within food circles on the reformulation and the production of new and improved food items. Much of this is achieved only through a close working relationship between academia and industry, in collaboration with the space agency itself.

1.9 THE DIFFERENCES BETWEEN FOOD DEHYDRATION METHODS

2-2 THE DIFFERENCES BETWEEN FOOD DEHYDRATION METHODS [16]

Technology	Energy Efficiency	Cost	Nutrient Retention	Product Quality	Suitability	Environmental Impact
Sun Drying	Low	Very Low	Low (due to variable drying conditions)	Inconsistent (depends on weather)	Suitable for low-value products, small-scale operations, regions with dry climates	High, due to reliance on weather and labour intensity
Freeze Drying	Low (high energy consumption)	High	Excellent (retains most nutrients, texture, and flavour)	Excellent (preserves texture and appearance)	High-value products (e.g., fruits, vegetables, pharmaceuticals)	High carbon footprint due to energy intensity
Vacuum Drying	Moderate (more energy-efficient than freeze drying)	Moderate	Good (preserves nutrients better than hot air drying)	Good (less shrinkage and flavour loss)	Suitable for heat-sensitive products like herbs, pharmaceuticals	It has a lower impact than freeze drying but still requires significant energy
Spray Drying	High (energy-efficient compared to freeze drying)	Moderate to Low	Moderate (some nutrient loss due to high temperatures)	Moderate (uniform particles, but possible flavour loss)	Suitable for liquids and powders (e.g., milk, fruit juices, instant coffee)	Lower environmental impact compared to freeze-drying
Microwave Drying	High (rapid drying process)	High	Moderate (may degrade some nutrients)	Moderate (non-uniform drying can affect texture)	Best for rapid, small-scale drying (e.g., fruits, grains)	Moderate, but could be improved with more efficient equipment
Tray drying	Moderate to High (depends on system design)	Moderate	Good (better than traditional hot air)	Good (uniform drying with controlled heat)	Suitable for bulk drying of fruits, vegetables, and grains	Moderate impact (energy-intensive but more efficient than traditional methods)

1.10 PACKAGING AND STORAGE CONSIDERATIONS

In addition to choosing the right treatment and drying parameters for a particular product, using appropriate packaging and storage is essential to the final quality of dehydrated food. Sealing is one of the most important concerns in packaging. Packages should be secured under a high vacuum with residual (reduced) oxygen and protected from moisture transmission [12]. The most effective method for packaging can depend on the product. When dehydrated foods are properly packaged, it is possible to maintain the original quality, such as flavor, color, and most of the nutrients, and prevent oxidative rancidity. Commonly used package materials for dried fruits include low-density polyethylene, high-density polyethylene, polyester, polypropylene, waxed papers, and cellophane. The use of moisture barrier materials such as metallized films is more protective from moisture than choosing individual materials, such as aluminum, Mylar, and laminates. Other advanced packaging methods, such as modified atmosphere packaging and micro-perforation, can also be used. It has been noted that light is a negative factor for the quality retention of dried fruits, and storage in the dark may provide a slight prolongation of shelf life [12].

Oxidation of dried fruit depends on the headspace gas in the package. Oxygen is considered a harmful factor for the preservation of color, flavor, and nutritional quality. Therefore, one of the most important packaging and storage considerations is to seal and store the product with minimal or no oxygen content. Along with oxygen impermeability and mechanical properties, packages must also withstand high temperatures and short-time applications for the pasteurization of dried fruit. Besides protecting the product from the immediate internal environment, packages are also required to isolate the dried food product from the external environment. If dried fruit absorbs moisture and is not properly resealed, it results in spoilage and contamination of the product. The package should be able to maintain the required atmosphere inside, protecting the food from becoming contaminated by the air and contaminants from outside. Once the package is damaged, the dried food is susceptible to recontamination [12]. Most consumers prefer packaging that is easy to open and close while keeping the product fresh. With increasing concern over microwave cooking, it is advantageous to develop packaging to prevent non-uniform rehydration of dried fruit. Even though the initial moisture of the product is low, if the product is rehydrated during cooking, it may spoil from mold growth. Various storage options should be considered when selling a product. Dried fruit can be stored refrigerated or in a frozen state, in coated corrugated cartons, in glass jars, or plastic zip bags. Research into new packaging options is currently underway. For instance, taste-released packaging films that are produced with either extrusion or cast films offer consumer-preferred eating quality compared to standard packaging. Strategically placed active ingredients within the packaging films are designed to effectively improve the shelf life or eating quality of dehydrated food products. This type of packaging claims a shelf-life extension of up to 10 times the current standard.

1.11 Regulatory and Safety Considerations

Several food safety laws and standards apply to the dehydration of foods. Specific regulations for dehydrated food products to ensure food safety in the European Union are very important [13]. Raw plant materials are easily contaminated with bacteria; therefore, the purpose of drying processes is not only to retain the nutritional value of dehydrated products but also to guarantee that the final products are free of contaminants. The implementation of process safety precautions in the food chain is determined by the Hazard Analysis Critical Control Points system, and maintaining the quality of raw materials is guaranteed by the Good Manufacturing Practice system. Dried food products should be given primary attention, and HACCP management should be integrated. Consumers have a right to safe food, and they are also interested in information labels that inform them of the risks associated with dried food. Consumers need information on nutritional or non-nutritional risks in dried food, which are addressed in the coding guidelines, and whether countries provide food protection, especially for dried foods. The different activities in the food chain mean that HACCP is implemented in different companies [13]. Generally, food safety regulations are put in place to protect the consumer from being seriously harmed. Therefore, the objective of food safety management is to minimize the risks to the consumer. Rules and laws now cover the entire food chain. The responsibility for the management of product safety within the food operation is increasingly placed on the business operator to ensure that the final product is safe to eat. Many standards are separate from exporters and importers, so the organization needs to be aware of these differences. All of the world's major food exporters and importers must also comply with HACCP regulations [13]. Complying with international requirements is the key to conducting successful international trade in food. The food industry must be aware of regulatory issues when purchasing imported materials to aid in monetization and changes in regulations that may affect their business.

1.12 Future Trends and Innovations in Food Dehydration

With the increasing amount of research being published each year, the field of food dehydration will likely have a significant impact on public health and safety in the near future. Factors such as a rise in demand for healthy and convenient foods, the increasing production and market demand for culturally unique foods, and the desire to reduce food waste by utilizing excess crops are expected to drive the need for dried food [14]. Dehydration offers benefits such as reduced sugar content and unique flavors of produce, but it also presents challenges such as oxidative deterioration and nutrient degradation. Advancements in the scientific and technical sectors aim to improve the food safety management of dried food. Growing trends in the industry include the development of high-protein, fiber-rich products, as well as efforts to enhance drying methods for energy efficiency and preservation of food quality. The use of smart packaging materials and the development of drying kinetics models are also contributing to the evolution of the dehydration industry. As the demand for high-quality, nutritious dried food increases, there is potential for growth and advancements in the future of the industry as efforts to meet consumer preferences and address post-harvest challenges continue [14].

1.13 CONCLUSION

In conclusion, dehydration is as important as it has been in the past or is still nowadays and will likely increasingly become in the future for different new commodities. Dehydration has passed from traditional methods to enable food preservation to modern methods in both respects of technologies and food for specific uses. Today, dehydration case studies are as they were yesterday, and they will probably become increasingly so in the future, based mainly on historical and traditional methods. They integrate all these techniques with modern approaches in drying, control, and regulatory issues, as well as food techniques for food application. The increasing demand on the market for fruits, vegetables, and air-dried edible flowers is the result of large-scale applications of these materials in different areas of human activities, such as pharmaceuticals, cosmetics, and the food industry, where the retention of physicochemical and nutritional characteristics are prerequisites. In these cases, they have some advantages: dehydrated products are lighter, better to store and transport, and need reduced packaging. Further, as reconstituted vegetable or fruit products, they are usable by kitchens to prepare soup and dessert, in restaurants, or by industries for the production of baby food, dietetic products, herbs, and snacks. The primary perspective that has come out from this quick overview of food dehydration and its different facets is to highlight the importance of this issue and the need for more and more scientific research studies in this field to widen our knowledge regarding this efficient food preservation technology today. In the era of both world trade, more similar dietary habits all over the world, and an increasingly ageing society, the demand for traditional dehydrated foods as well as for new-generation, personalized, edible products will undoubtedly increase. This is why research and development in the field of food dehydration is an important and, at the same time, challenging issue for today and in the near future.

CHAPTER 2

DESIGN AND DEVELOPMENT OF THE FOOD DEHYDRATOR

2 CHAPTER 2: DESIGN AND DEVELOPMENT OF THE FOOD DEHYDRATOR

2.1 INTRODUCTION

Food preservation is an essential aspect of minimizing waste and ensuring food security, particularly in regions like Algeria, where agricultural production is seasonal. Dehydration a widely used preservation method, offers a practical solution by removing moisture to prevent microbial growth and spoilage. However, conventional dehydrators often face challenges such as high energy consumption, inconsistent drying results, and limited suitability for small-scale operations.

This chapter outlines the design and development of an energy-efficient food dehydrator tailored to address these issues. The objectives of the Project are as follow:

- **Energy Efficiency**: Reducing energy consumption by up to 50% through optimized programming and the use of high-quality insulation materials.
- **Customization**: Enabling users to adjust temperature manually and drying time for various food products.
- **Local Production**: Utilizing locally sourced materials to lower production costs and encourage sustainable development practices.

The dehydrator integrates advanced electronic controls, such as a microcontroller for precise temperature regulation, and a robust mechanical design to ensure uniform drying across multiple trays. By optimizing airflow and leveraging innovative energy-saving strategies, this system is designed to surpass conventional models in efficiency and usability while meeting the needs of small-scale producers and households.

This chapter will detail the technical specifications of the system, including its components, mechanical and electronic designs, the prototyping process, and the challenges encountered during development. The innovative aspects of the design and the solutions implemented to enhance performance will also be highlighted.

2.2 Technical Specifications

The food dehydrator was designed to balance performance, energy efficiency, and usability. This section details the key components and their roles in achieving these objectives.

2.2.1 Heating System

The heating system is the core component responsible for raising the air temperature to facilitate moisture removal from food.

- **Heating Element**: An electric coil heater is used to provide consistent and controllable heat.

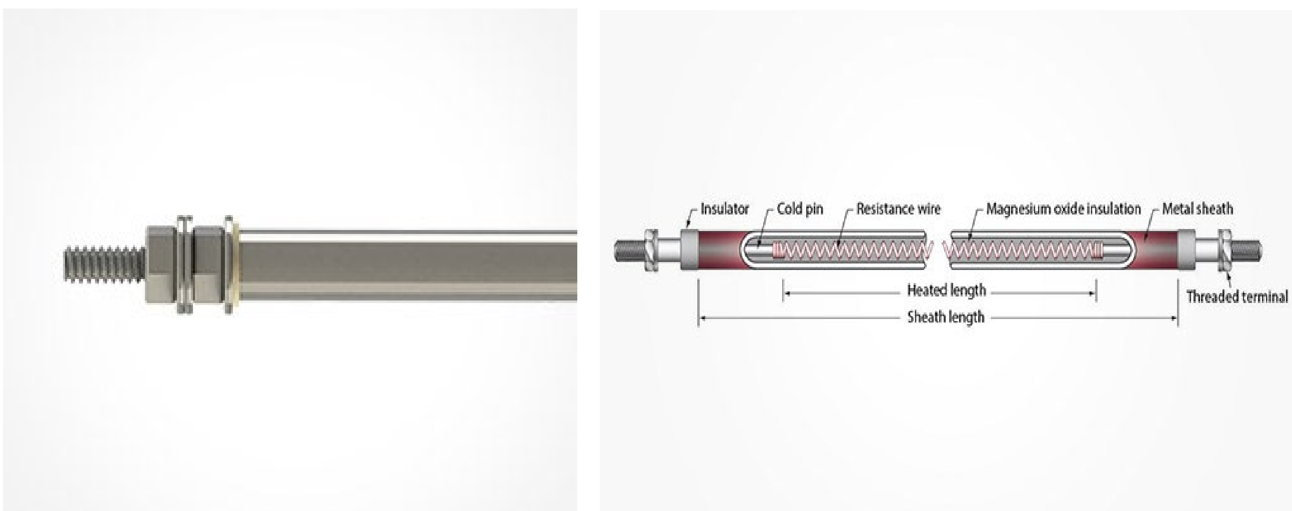

Figure 8 heating element parts

- **Temperature Range**: The system supports adjustable temperatures between 20°C and 90°C, suitable for a variety of food products.
- **Thermal Control**: A sensor connected to the microcontroller ensures that the temperature remains stable within the user-set range.

2.2.2 Air Circulation System

Uniform airflow is critical to achieve consistent drying across all trays.

- **Fans**: A series of energy-efficient axial industrial metal fans are positioned to circulate heated air evenly across trays.

Figure 9 FAN

- **Duct Design**: Optimized duct placement minimizes heat loss and prevents hotspots, ensuring uniform drying.

2.2.3 Insulation

High-quality and expansive brand insulation is used to prevent heat loss and enhance energy efficiency.

- **Material**: One of the secrets of this project is the insulation that is put in the walls of the dehydrator.
- **Effectiveness**: This reduces energy consumption by maintaining internal temperatures with minimal heat dissipation.

2.2.4 Electronic Control Unit

The dehydrator incorporates a microcontroller-based control system to enable precise temperature and timer adjustments.

- **Controller**: An Arduino Uno is used as the central control unit:
- Arduino Uno is a microcontroller board based on the ATmega328P. It has 14 digital input/output pins (of which 6 can be used as PWM outputs), 6 analogue inputs, a 16 MHz quartz crystal, a USB connection, a power jack, an ICSP header and a reset button. It contains everything needed to support the microcontroller; simply connect it to a computer with a USB cable or power it with an AC-to-DC adapter or battery to get started **[7].**

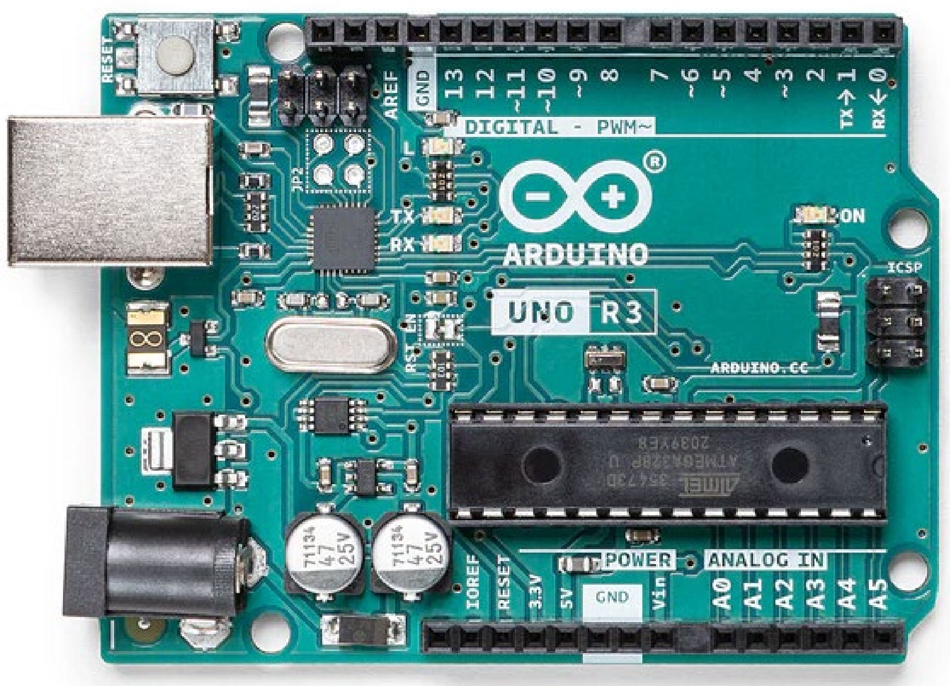

Figure 10 ARDUINO Uno board

Table 3.1 The specifications of the Arduino UNO:

3-1 The specifications of the Arduino UNO ***[7]***

Microcontroller	ATmega328P
Operating Voltage	5V
Input Voltage (recommended)	7-12V
Input Voltage (limit)	6-20V
Digital I/O Pins	14 (of which 6 provide PWM output)
PWM Digital I/O Pins	6
Analog Input Pins	6
DC Current per I/O Pin	20mA
DC for 3.3V Pin	50mA
Flash Memory	32KB (Atmega328p)
SRAM	2KB (Atmega328p)
EEPROM	1KB (Atmega328p)
Clock Speed	16MHz
Length	68.6 mm
Width	58.4 mm
Weight	25

- **Solid state relay**: Arduino uno can't control the heating system and airflow system directly. It needs relays to control and power the tow systems.

Figure 11 Solid State Relay SSR

- **Control Features** :
  - Manual temperature adjustment via an LCD and control buttons.

  LCD 20x4: RC2004B is a 20 x 4-character LCD module with module dimensions 77.0 x 47.0 mm. The default interface of the RC2004B series is 6800 with built-in IC ST7066, which requires interfaces such as SPI or I2C.LCD module powered by 5V.

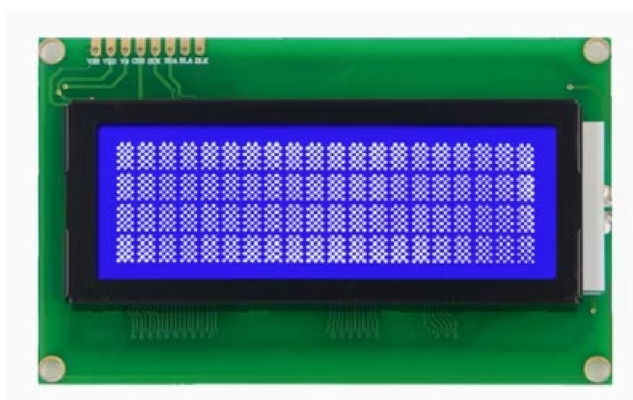

*Figure 12 LCD 20*4*

Figure 13 BUTTON SWITCH

- Timer settings to allow users to set drying durations ranging from 1 to 24 hours.

2.2.5 Power Supply and Energy Management

Energy efficiency was prioritized in the design of the power system.

- **Power Source**: Standard 220V AC power input with a built-in power converter for safe and stable operation of electronic components.
- **Energy Management**: Advanced programming ensures that the heater and fans operate cyclically to minimize energy consumption without compromising drying performance.

2.2.6 Tray Design

The mechanical design of the trays facilitates effective drying and maximizes capacity.

- **Material**: Food-grade stainless steel ensures durability and hygiene.

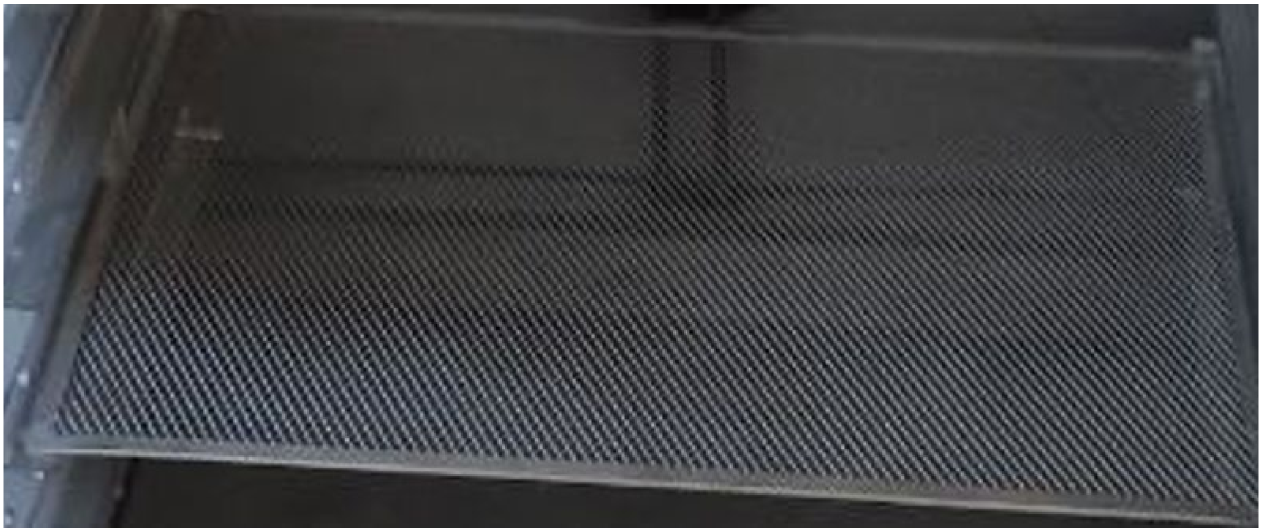

Figure 14 Stainless steel tray

- **Spacing**: Adjustable tray spacing allows for different food sizes ”60cm *40cm”.
- **Perforations**: Trays are perforated to allow unrestricted airflow across food surfaces.

2.2.7 User Interface

A simple and intuitive user interface makes the dehydrator accessible to a wide range of users.

- **Display**: An LCD of the current temperature and remaining drying time.
- **Controls**: Push buttons allow for easy adjustment of temperature and timer settings and stop-start drying process.

2.3 SYSTEM DESIGN

The system design of the food dehydrator incorporates mechanical and electronic elements, working together to ensure energy-efficient and uniform drying. This section details the layout, material selection, and operational flow.

2.3.1 Mechanical Design

The mechanical structure of the dehydrator was carefully engineered to maximise drying efficiency while minimizing energy loss.

- **Housing** :
  - The external body is constructed from stainless steel, ensuring durability and resistance to corrosion.
  - Insulation of the interior walls to reduce heat loss.
- **Tray Configuration** :
  - The dehydrator includes 9 perforated trays, allowing hot air to circulate freely around food items.
  - Adjustable spacing accommodates various food types and quantities.
- **Airflow Optimization**:
  - A fan-and-duct system evenly distributes heated air across all trays.
  - Air vents are strategically positioned to avoid recirculating moisture-laden air.

2.3.2 Electronic Design

The electronic system integrates sensors, controls, and actuators managed by a microcontroller for precise operation.

- **Control Board** :
  - The Arduino Uno serves as the brain of the system.
  - A relay board interfaces the microcontroller with the heating element and fans.
- **Temperature Regulation** :
  - A SENSOR give info about air temperature to the microcontroller to maintain user-defined levels.
- **User Interface** :
  - LCD display real-time temperature and timer status.
  - Buttons allow users to set temperature and time parameters easily and stop-start the drying process.

- **Power Regulation** :
  - AC to DC regulator module reduces input voltage for safe operation of the electronics.

2.3.3 System Integration

The integration of mechanical and electronic components ensures smooth operation and user control.

- **Workflow** :

  1. The user sets the desired temperature and time using the interface.
  2. The microcontroller activates the heating element and fans.
  3. Sensors continuously monitor the internal environment and adjust the heater and fans.
  4. Once the timer ends, the system shuts off automatically.

- **Safety Features** :
  0. Overload protection cuts power if Ampere exceeds safe limits using fuses.

2.3.4 Block Diagram

A block diagram illustrates the interaction between components:

1. **User Input** (temperature and timer settings).
2. **Microcontroller** (processing and control).
3. **Heating System** (ensuring air heating).
4. **Fan System** (ensuring airflow).
5. **LCD Display** (real-time data and display data).
6. **Temperature Sensor** (give info about air heated).

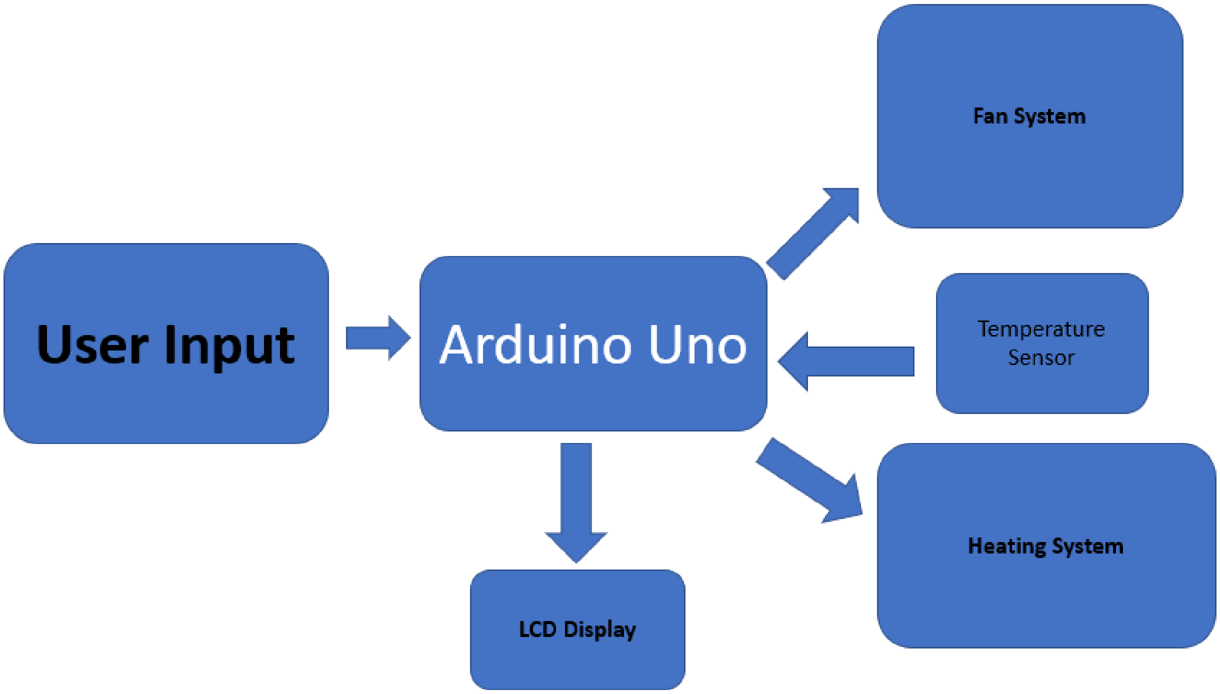

Figure 15 SYSTEM Block Diagram

2.3.5 ORGANIZATION CHART 'Flowchart' :

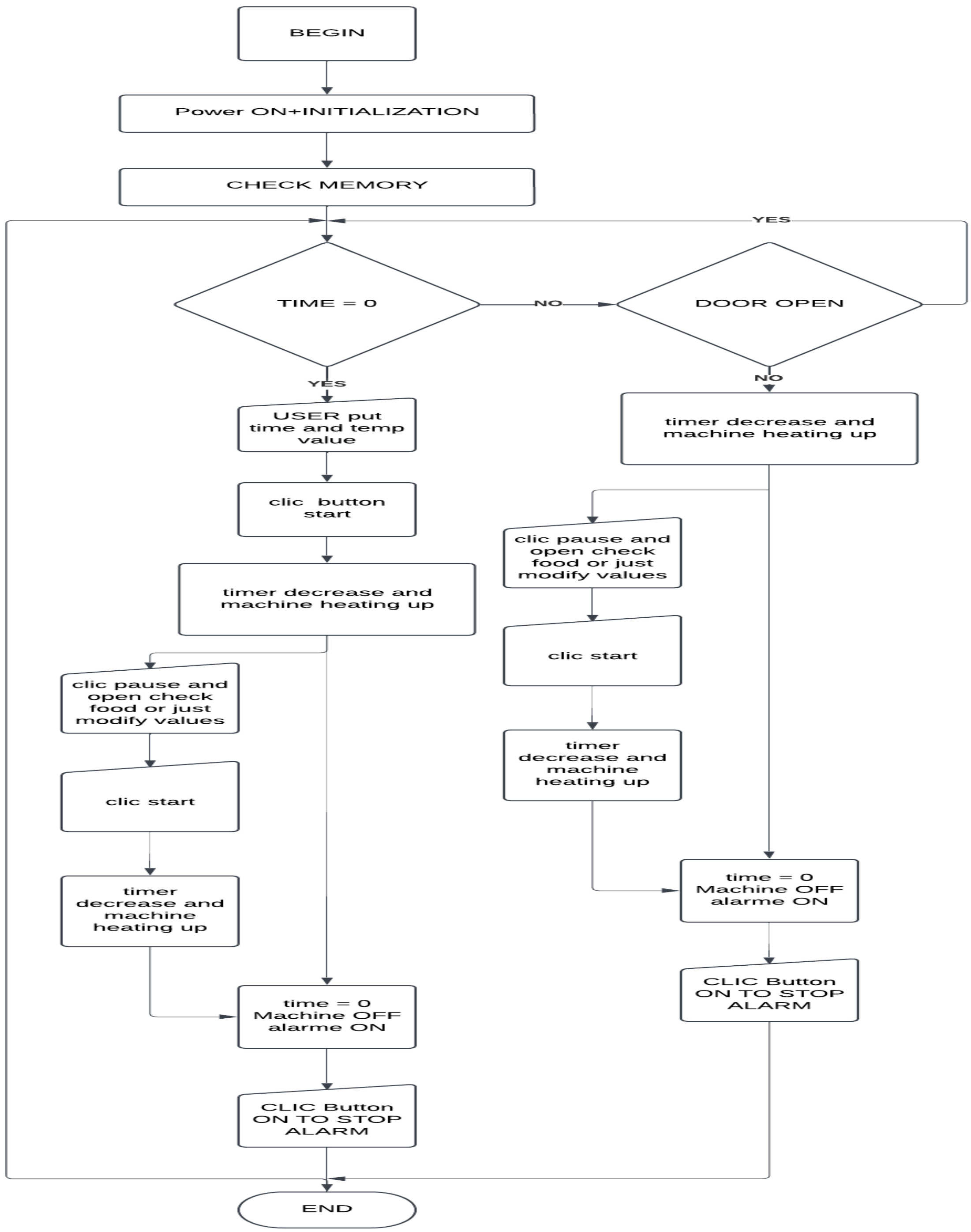

Figure 16 Machine working Flowchart

2.3.6 Features and Benefits

- **Uniform Drying**: Optimized airflow ensures consistent results across trays.
- **Energy Efficiency**: Insulation and control minimize energy usage.
- **User Customization**: Manual controls allow precise drying for different food types.

2.4 Prototyping Process

This section explains the step-by-step process undertaken to build and test the prototype of the food dehydrator. It highlights the iterative development stages, material selection, and assembly process.

2.4.1 Initial Conceptual Design

The first stage focused on creating a blueprint for the dehydrator.

- **Sketching and Planning** :
  - Initial hand-drawn sketches outlined the overall structure, including housing dimensions, tray placement, and airflow paths.
  - CAD software was used to refine these designs, enabling precise measurements and 3D modelling for visualization. We are going to use SOLIDWORKS.

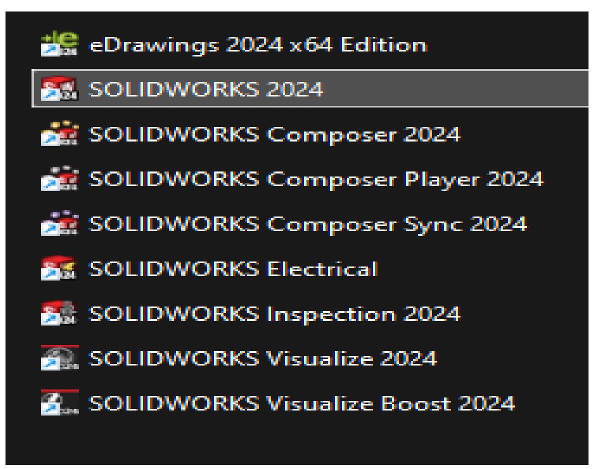

Figure 17 SolidWorks Icon

- **Key Design Features** :
  - Compact size suitable for household and small-scale operations.

- Layered trays for maximum drying capacity.

2.4.2 Material Selection

Materials were chosen based on durability, thermal efficiency, and local availability:

- **External Housing**: Stainless steel for robustness and corrosion resistance.
- **Insulation**: reduce heat loss and improve energy efficiency.
- **Trays**: Food-grade stainless steel with perforations for optimal airflow.
- **Electronics**: Locally sourced Arduino Uno, fans, heating elements, and relay boards.

2.4.3 Mechanical and Electrical Assembly

- **Frame Construction** :
  - Stainless steel sheets were cut and welded to form the external housing.
  - Insulation was applied to the interior walls before sealing.
- **Tray Installation** :
  - Adjustable tray supports were added to accommodate various food sizes.
  - Trays were securely slotted to ensure airflow consistency.
- **Electronics Integration** :
  - The Arduino Uno was programmed and connected to relays, sensors, and user interface components.
  - Fans and heaters were installed and wired to the power supply, with circuits tested for stability.

2.4.4 Iterative Testing and Refinement

The prototype underwent several rounds of testing to ensure functionality and efficiency:

- **Initial Tests** :
  - The system was tested for basic operation, including heating, airflow, and user interface responsiveness.
- **Performance Adjustments** :
  - Adjustments were made to airflow paths to eliminate hotspots and ensure uniform drying.
  - Insulation layers were optimized to reduce energy consumption further.

- **Programming Refinements** :
  - The Arduino code was updated to improve temperature stability and precise timer functionality using Arduino IDE for programming boards **[7].**

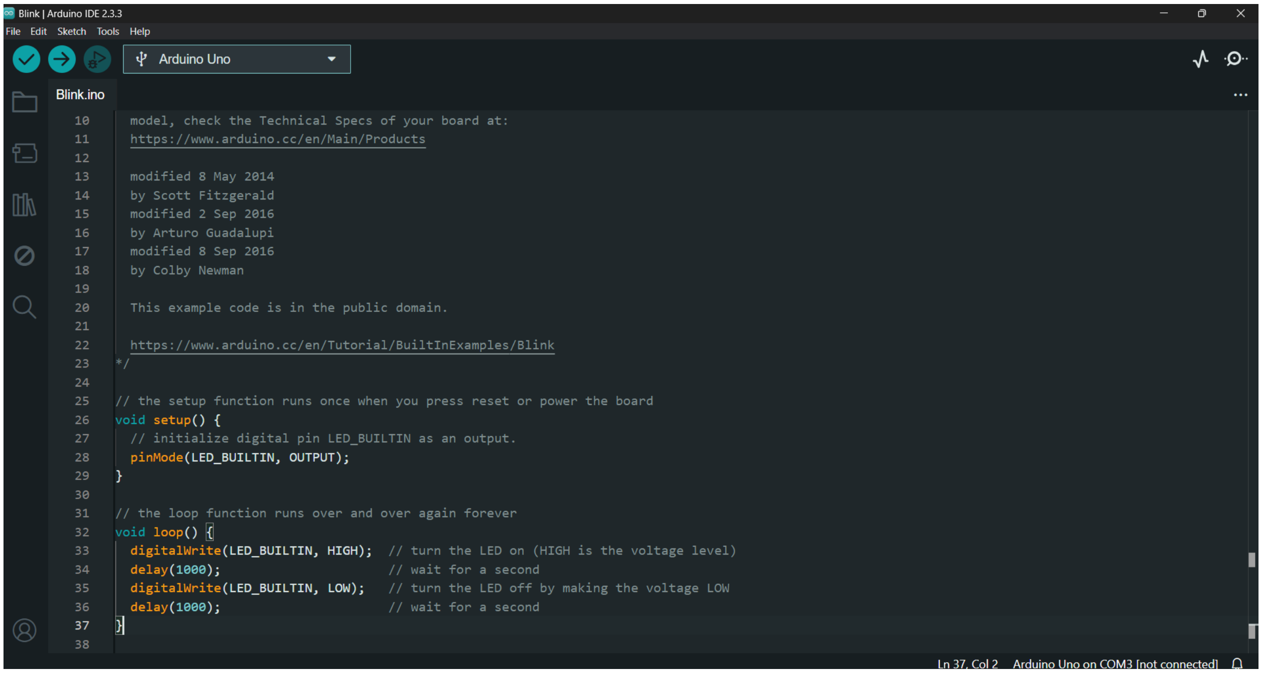

Figure 18 Arduino IDE

2.5 Conclusion:

The development of the energy-efficient food dehydrator presented in this chapter demonstrates a systematic approach to addressing the challenges of traditional dehydration methods. By combining advanced mechanical and electronic designs, the system achieves significant improvements in energy efficiency, drying uniformity, and user customization.

The integration of high-quality insulation and optimized airflow systems plays a central role in reducing heat loss and ensuring consistent drying performance. The use of a microcontroller-based control system, with manual adjustments for temperature and timer settings, provides flexibility and adaptability for a variety of food products, making it user-friendly for small-scale producers and households.

Challenges such as heat leakage, uneven airflow, and component availability were effectively addressed through iterative testing and design refinements. The energy efficiency analysis confirms the system's success in achieving a 50% reduction in energy consumption compared to conventional models, supporting its environmental and economic viability.

In conclusion, the design and development of this food dehydrator mark a significant step toward sustainable food preservation solutions. It offers a practical, locally manufacturable alternative that aligns with Algeria's goals for reducing food waste and promoting efficient energy use. This foundation sets the stage for the next chapter, where the system's performance will be rigorously tested and validated under real-world conditions.

CHAPTER 3

THE STATE OF THE ART ABOUT FOOD DEHYDRATION

3 CHAPTER 3: DESIGN AND PROTOTYPE VALIDATION

3 INTRODUCTION

Testing and validation are pivotal stages in the development of any product, serving to confirm that design objectives are achieved while uncovering opportunities for refinement. In the case of the food dehydrator, these phases were essential for evaluating its performance, energy efficiency, and usability under practical operating conditions. The primary goal was to assess the system's capability to uniformly dry various food products while achieving the project's ambitious target of significantly reducing energy consumption.

To ensure a comprehensive evaluation, the testing process included a diverse range of food types such as fruits, vegetables, and herbs, selected for their distinct moisture content and drying characteristics. Key performance metric such as drying time, moisture reduction, and energy usage were meticulously analyzed to gauge the system's overall efficiency. Furthermore, user interaction tests were conducted to assess the intuitiveness and functionality of the control panel and interface, ensuring the dehydrator meets the needs of both household users and small-scale producers.

This chapter details the experimental setup, testing methodology, and the outcomes of these evaluations. It also explores the challenges encountered during the testing process and the iterative improvements made to address them. Ultimately, the findings validate the system's performance and demonstrate its feasibility for broader application, aligning with the overarching objectives of energy efficiency and user accessibility.

3.1 GENERAL CONCEPT OF THE PROJECT

The primary objective of this phase is to validate the performance and effectiveness of the food dehydrator through comprehensive testing and analysis. This entails designing and executing operating tests that replicate real-world conditions to evaluate the system's ability to achieve its design goals, including energy efficiency, uniform drying, and user friendliness.

A key focus of this chapter is the systematic setup of controlled experiments to measure critical performance metrics, such as energy consumption, drying time, and moisture removal across diverse food types including fruits, vegetables, and herbs. The system's consistency in temperature regulation and its ability to ensure uniform drying across multiple trays are also closely examined, with an emphasis on identifying areas for improvement and optimizing overall performance.

In addition to performance tests, user interaction evaluations are carried out to ensure the dehydrator is intuitive and easy to use for both household consumers and small-scale commercial operators. Feedback from these tests informs refinements to the interface and usability, aligning with the project's overarching goal of delivering a practical, energy-efficient solution for food preservation.

This chapter underscores the critical role of systematic testing in validating the dehydrator's capabilities, addressing design challenges, and ensuring its readiness for real-world applications.

3.2 THE FINAL DESIGN ON SOLIDWORKS

After extensive effort and significant time dedicated to developing and refining the design, several iterations were produced. Below are some of the key designs that emerged during this process:

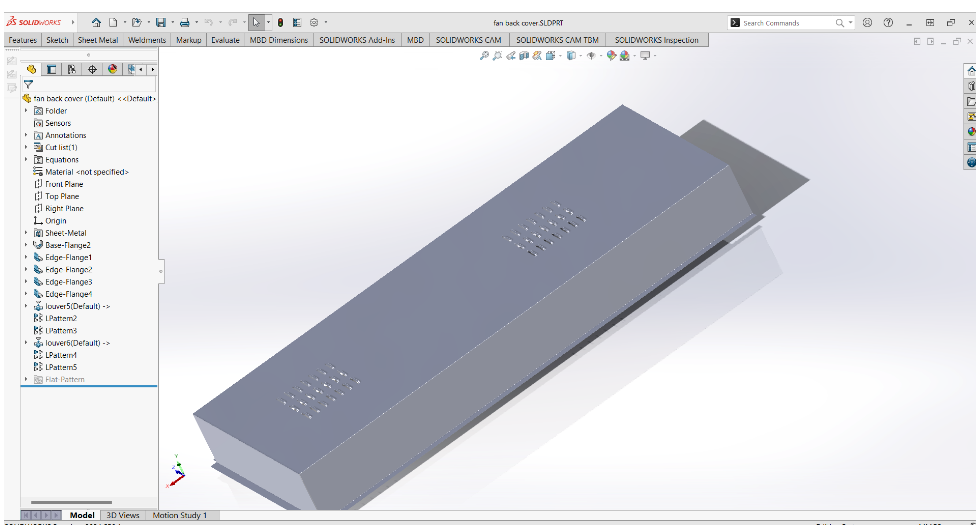

Figure 19 design the back of the machine

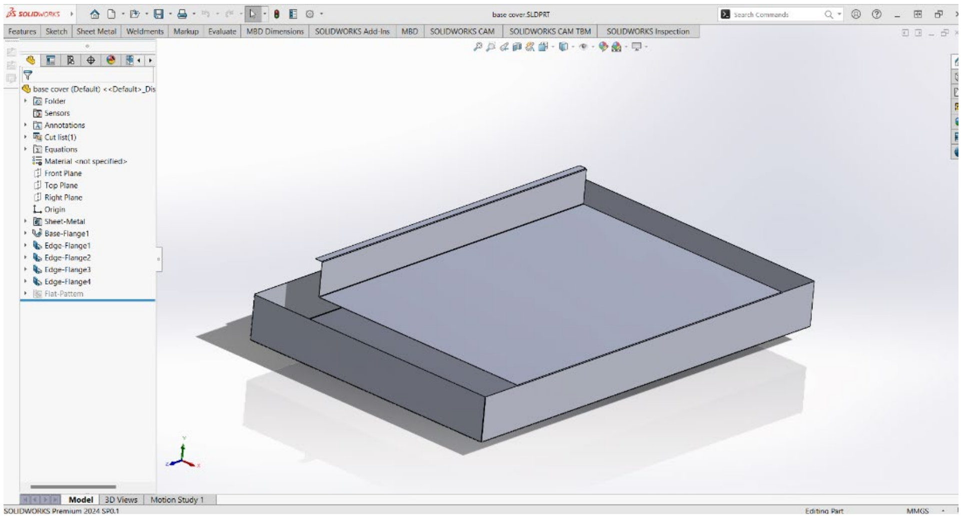

Figure 20 design the BASE of the machine

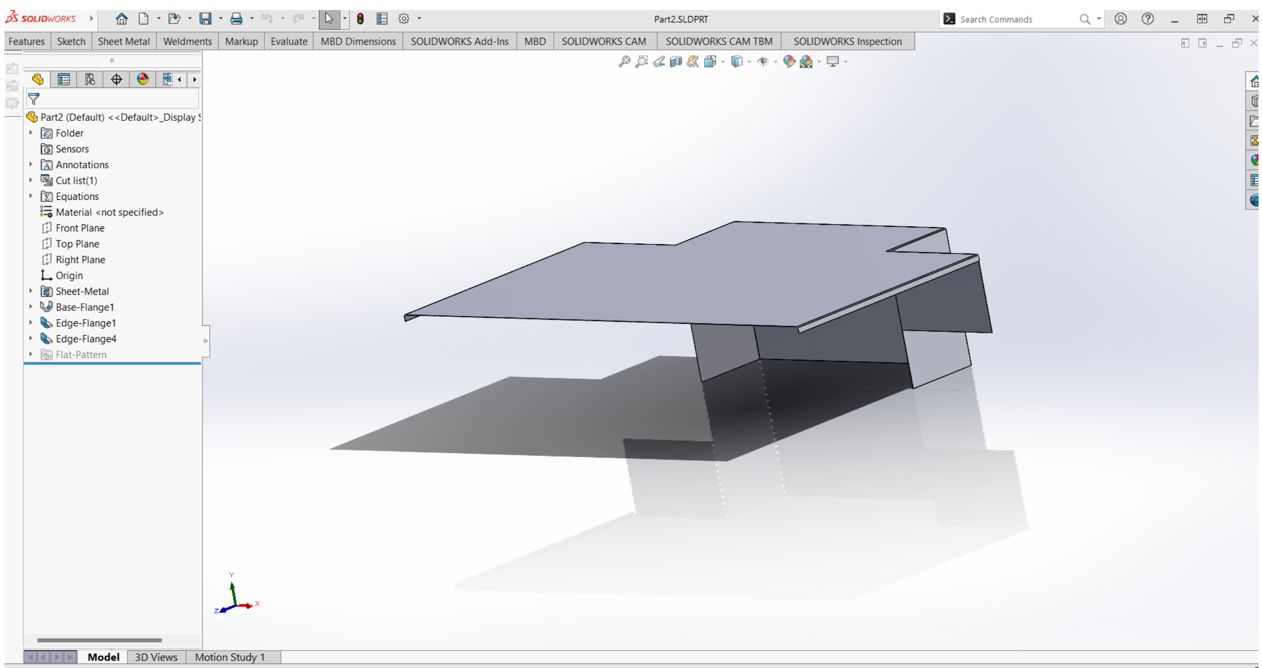

Figure 21 design the TOP COVER of the machine

These are some components of the machine, however, not all details can be disclosed at this stage, as we are in the process of applying for a patent for this design.

3.3 MAKE DATASHEETS IN SOLIDWORKS

it’s very important to create datasheet for every part of the machine to print them and take it to the specialist maker so he will know every detail he need to not make any errors in cutting or bending process, there is some examples about datasheets:

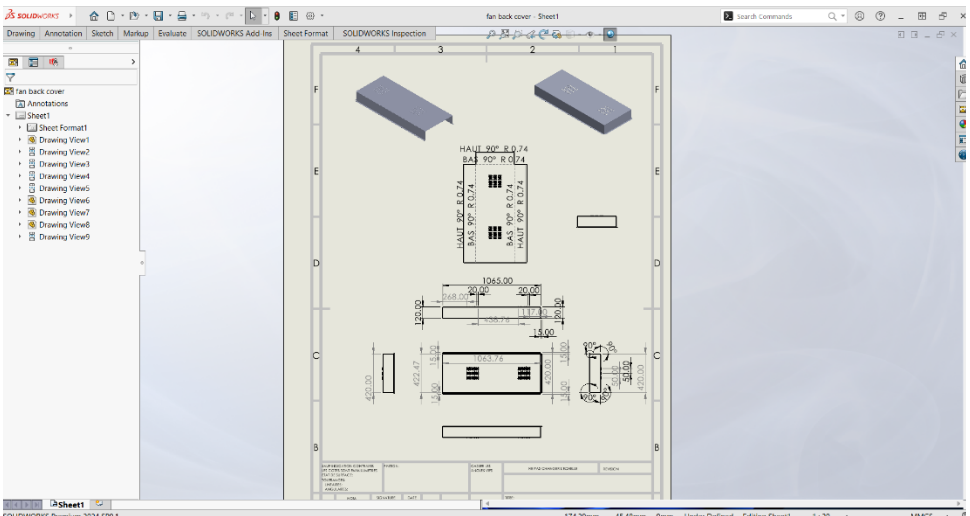

Figure 22 DATASHEET OF THE BACK PART

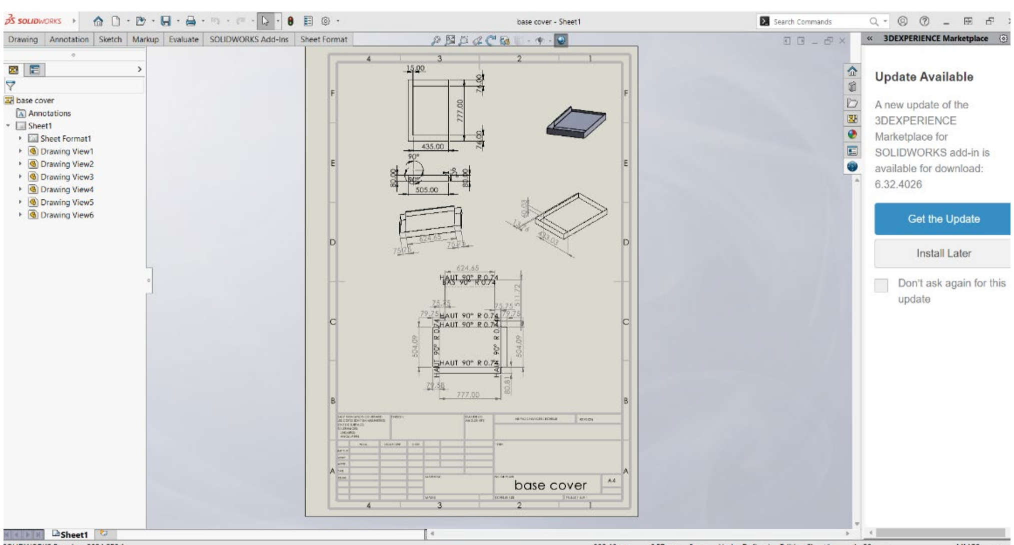

Figure 23 DATASHEET OF THE BASE PART

3.4 MANUFACTURING PARTS

After providing the datasheet to the manufacturing specialist, he began the process of fabricating the parts. To achieve precise cuts and bends, he utilized advanced industrial equipment, including CNC plasma cutting machines and bending machines, which are capable of working with stainless steel sheets.

Figure 24 CNC BLASMA AND BENDING MACHINE

My machine parts after manufacturing:

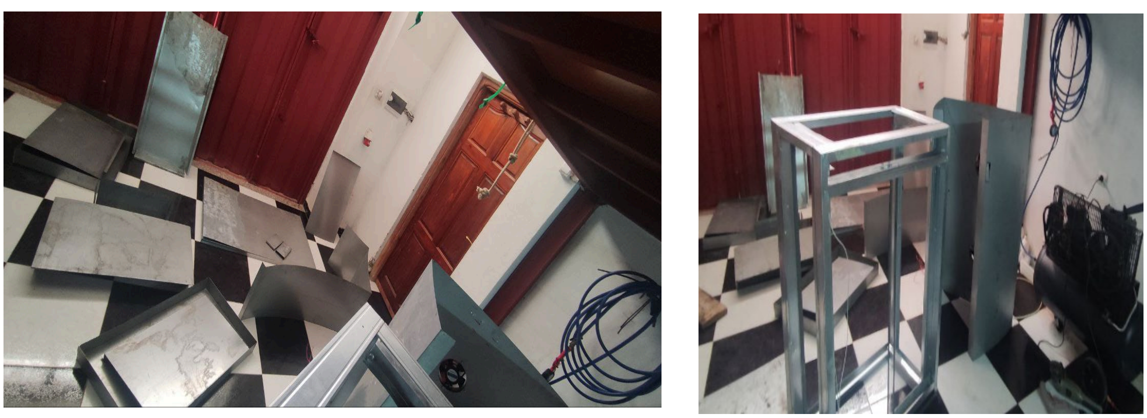

Figure 25 My machine parts after manufacturing

3.5 RESULTS AFTER ASSEMBLING THE PARTS:

Figure 26 RESULTS AFTER ASSEMBLING THE PARTS

3.6 DEVELOPING AND CREATING THE CIRCUIT BOARD:

The basic tests were made with an Arduino Uno board and a lot of wires between it and other components on the test board that caused a lot of problems like sudden wires disconnected and signal noises, this is the image of the control unit:

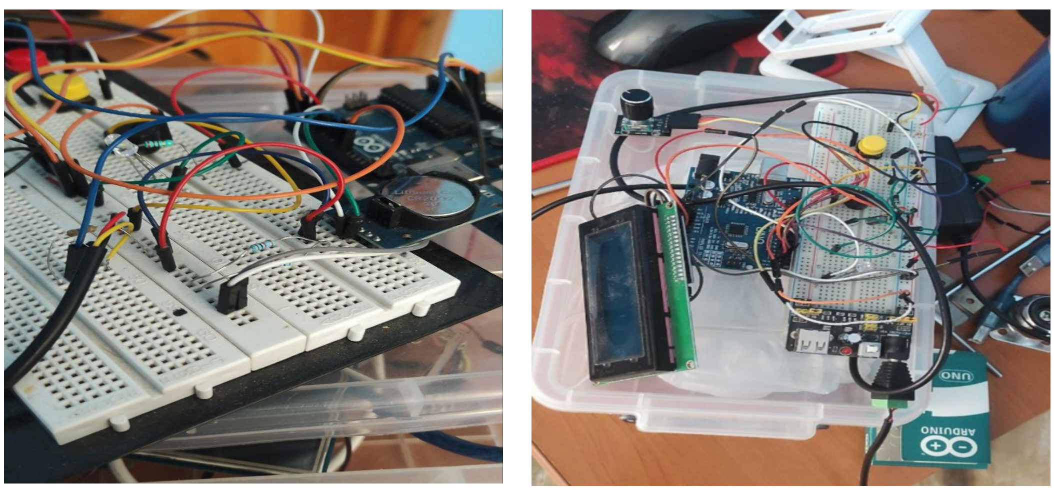

Figure 27 The first control unit

3.6.1 Using software PROTEUS to design new version of the Control Unit:

I applied some new modification in circuit board to eliminate the old problems like:

- Add LM337 to power supply section to provide a stable voltage to sensible component.
- Replace the RTC 3231 with a developed circuit build in, to ensure long life data saving

- .
- Eliminate the wiring problem by using just microcontroller atmega328p in PCB.
- Make professional design with high quality connecters to avoid noise.

3.6.2 PROTEUS INTERFACE

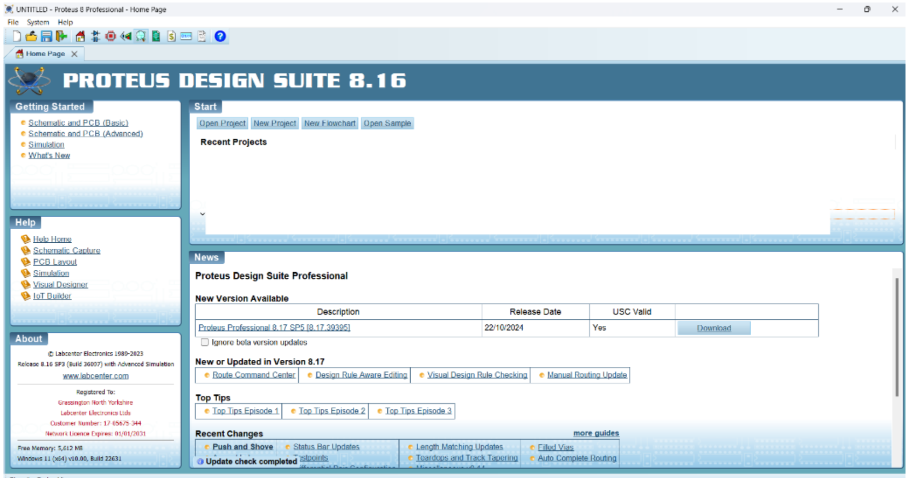

Figure 28 PROTEUS INTERFACE

3.6.3 SCHEMATIC PART

The circuit:

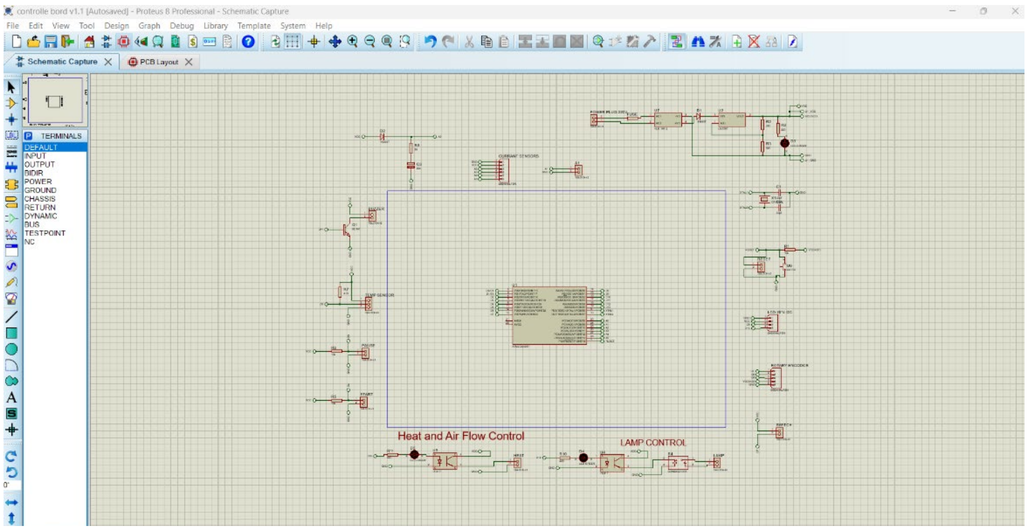

Figure 29 SCHEMATIC PART

3.6.4 PCB LAYOUT PART

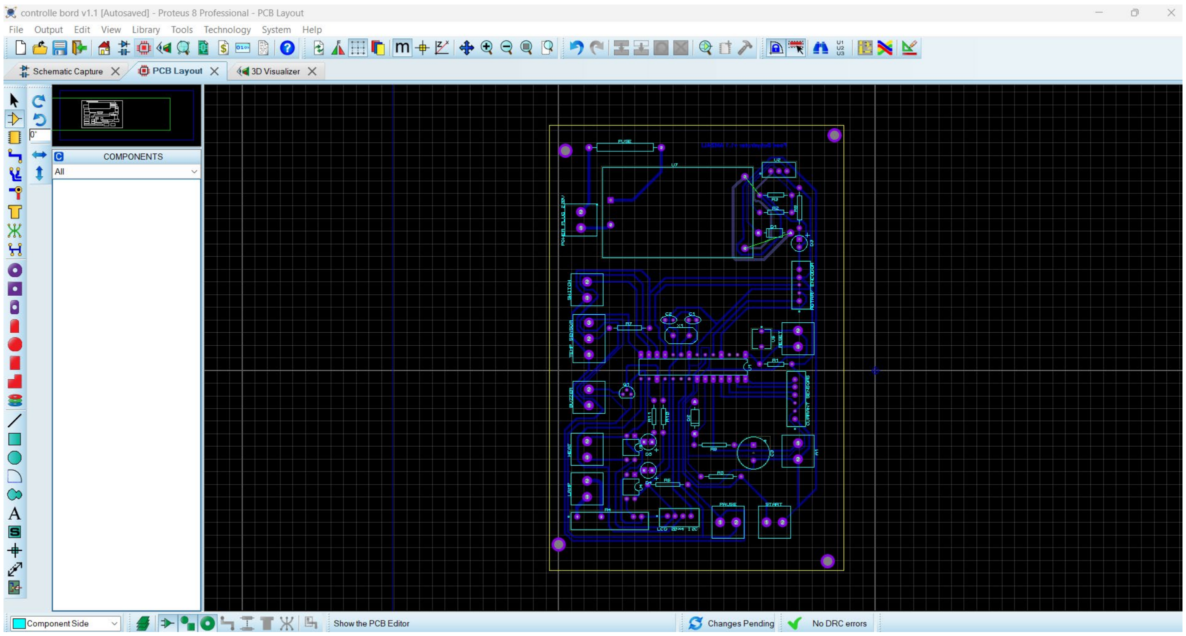

Figure 30 PCB LAYOUT PART

3.6.5 3D Visualize part

Is this part we see the final PCB board in 3D:

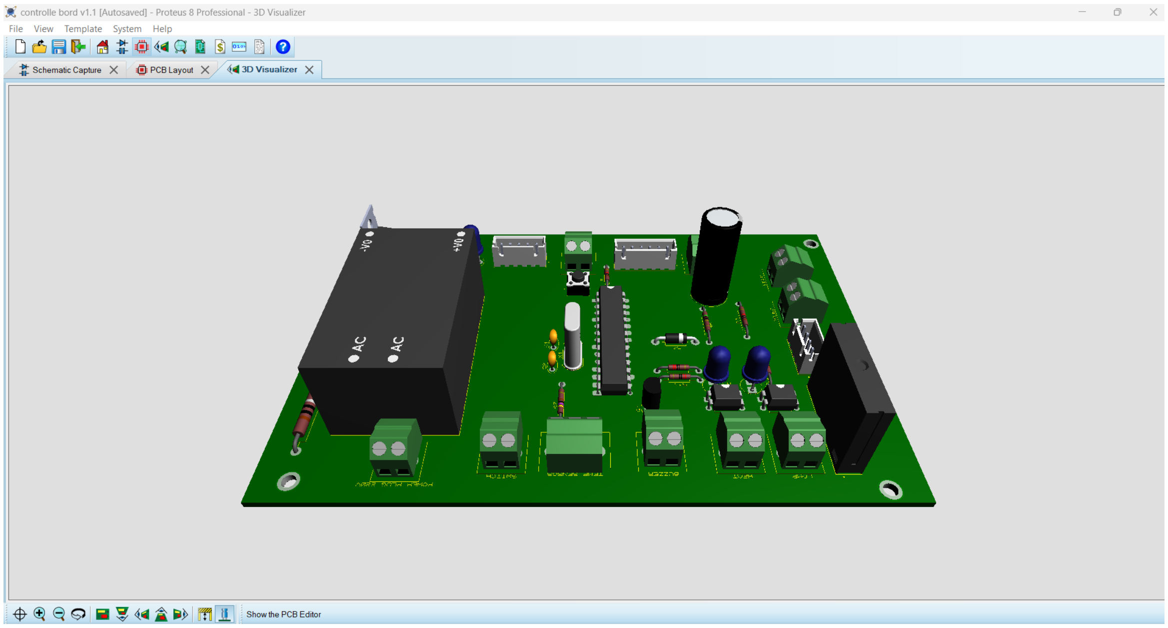

Figure 31 3D Visualize part

3.6.6 Printable sheet of the circuit

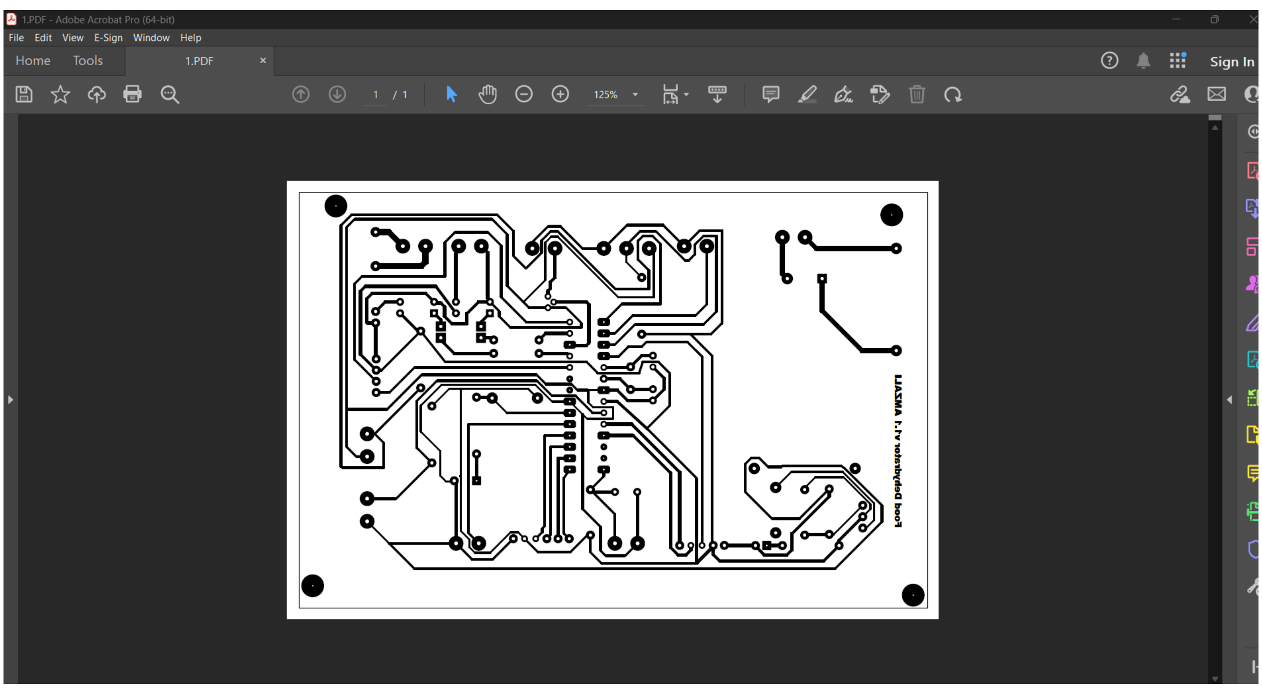

Figure 32 Printable sheet of the circuit

3.6.7 The steps how we make the PCB in lab

Impression Cutting:

We print the circuit on heat transfer paper with laser printer, then we cut the Epoxy/copper plate to the dimensions of the circuit, next We put the paper on the cutted sheet of copper plate, then we put the paper on the cutted sheet of copper plate.

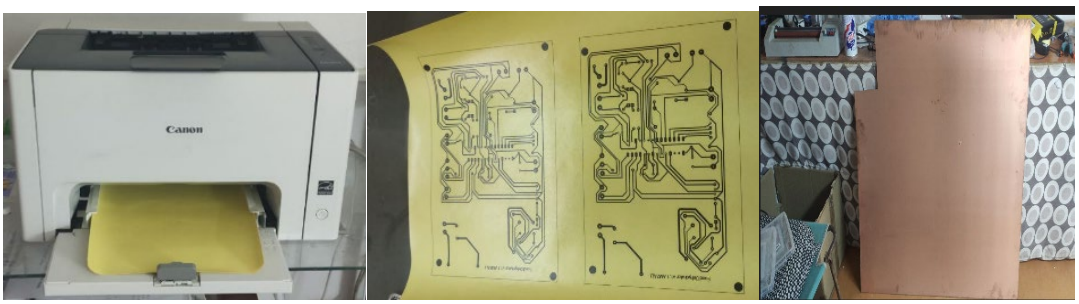

Figure 33 first step needed part for pcb creation

TRANSFER HEAT FOR BOTTOM LAYER:

We put the plate in the laminator machine after the heat up and it automatically pressed and transferred the circuit on the plate after rolling it in and out 3 or 4 times, and operation will take just 2 min max for good transfer

Figure 34 laminator machine for heat transfer

PCB ETCHING DRILLING:

Carefully we put the hot plate in the acid 'Ferric chloride ($FeCl_3$)' pool, The machine will heat the acid and move the plate to accelerate the operation, will take off the copper after 10 to 15 min, take off the plate wash it with water and clean it with surgical alcohol or benzylic solution, Cleaning with water, Drill the PCB AND CUT THE EDGES

Note: you must pay attention and use gloves and a mask to protect yourself.

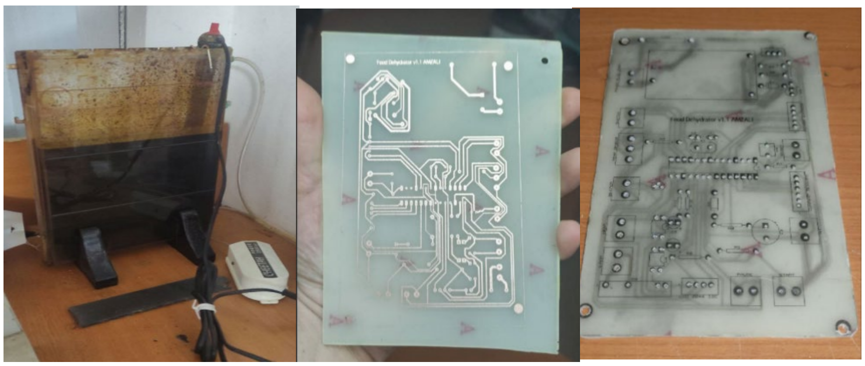

Figure 35 PCB ETCHING DRILLING

SOLDERING OPERATION:

Use a soldering iron to solder the components on the PCB

Note: During this operation, the safety instructions must be followed.

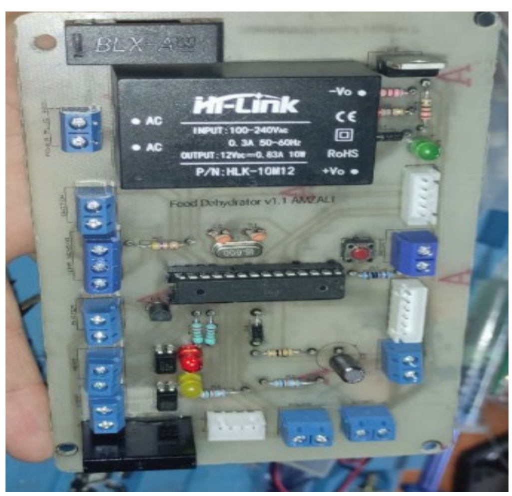

Figure 36 PCB WITH SOLDRING COMPONANT ON IT

NOW THE PCB READY.

3.6.8 urning the bootloader on the Microcontroller atmega328p:

Migrating an Arduino board to a standalone microcontroller on a breadboard, this explains how to migrate from an Arduino board to a standalone microcontroller on a breadboard, but uses an Arduino board to program the ATmega328P on the breadboard **[8]**.

Unless you choose to use the minimal configuration described at the end of this part, you'll need four components (besides the Arduino, ATmega328P, and breadboard):

- 16 MHz Crystal
- 10k resistor
- two 18 to 22 picofarad (ceramic) capacitors.

Burning the Bootloader

If you have a new ATmega328P (or ATmega168), you'll need to burn the bootloader onto it. You can do this using an Arduino board as an in-system program (ISP) **[8].** If the microcontroller already has the bootloader on it (e.g. because you took it out of an Arduino board or ordered an already-bootloaded ATmega), you can skip this section.

To burn the bootloader, follow these steps:

1. Upload the ArduinoISP sketch onto your Arduino board. (Need to select the board and serial port from the Tools menu that correspond to your board.)
2. Wire up the Arduino board and microcontroller as shown in the diagram.
3. Select "Arduino Duemilanove or Nano w/ ATmega328" from the Tools > Board menu. (Or "ATmega328 on a breadboard (8 MHz internal clock)" if using the minimal configuration described below.)
4. Select "Arduino as ISP" from Tools > Programmer
5. Run Tools > Burn Bootloader

You should only need to burn the bootloader once. After you've done so, you can remove the jumper wires connected to pins 10, 11, 12, and 13 of the Arduino board.

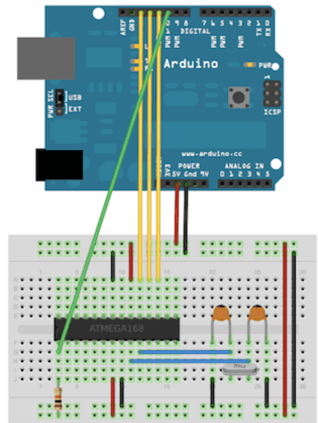

Figure 37 WIRING SCHEMATIC NEEDED FOR Bootloader

Using an Arduino board to burn the bootloader onto an ATmega on a breadboard.

3.6.8.1 Uploading Using an Arduino Board

Once your ATmega328P has the Arduino bootloader on it, you can upload programs to it using the USB-to-serial converter (FTDI chip) on an Arduino board**[8]**. To do, you remove the microcontroller from the Arduino board so the FTDI chip can talk to the microcontroller on the breadboard instead. The diagram shows how to connect the RX and TX lines from the Arduino board to the ATmega on the breadboard. To program the microcontroller, select "Arduino Duemilanove or Nano w/ ATmega328" from the Tools > Board menu (or "ATmega328 on a breadboard (8 MHz internal clock)" if you're using the minimal configuration described below). Then upload as usual.

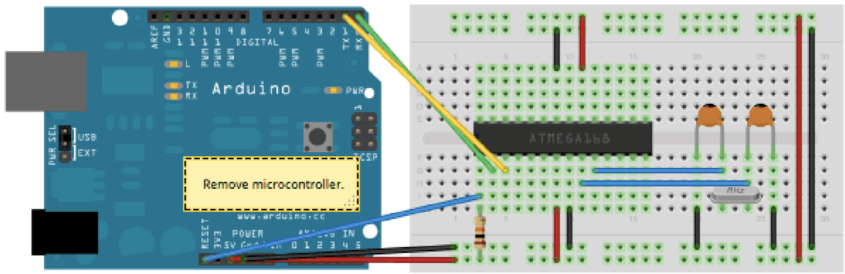

Figure 38 WIRING SCHEMATIC NEEDED TO BURN Bootloader without atmega328p

Uploading sketches to an ATmega on a breadboard. Remember to remove the microcontroller from the Arduino board!

-UPLOAD THE PROJECT CODE ON THE MICROCONTROLLER USING ARDUINO IDE.

-NOW THE ATMEGA328P READY TO BE IN THE NEW PCB.

3.7 ASSEMBLING AND WIRING THE FINAL VERSION OF THE CONTROL UNIT WITH HER ACCESSORIES

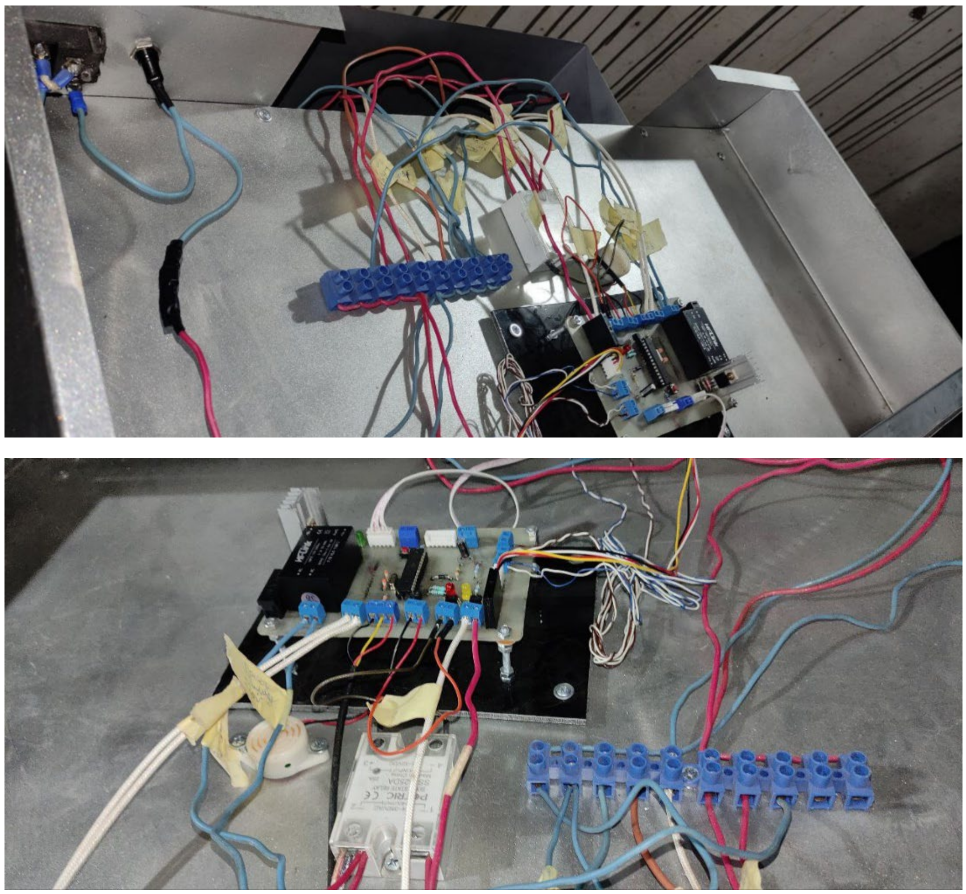

Figure 39 WIRING THE FINAL VERSION OF THE CONTROL UNIT WITH HER ACCESSORIES

3.8 PLACING THE USER INTERFACE

Figure 40 MACHINE USER INTERFACE

3.9 THE FINAL VERSION OF THE PROTOTYPE

Figure 41 REAL IMAGES OF THE FINAL PROTOTYPE

Discussions: as we see in the last figure the last prototype from different angles

we are very satisfied about our results because we hitting all the target that we want.

3.10 TESTS RESULTS WITH CALCULATION

The tests and measurements were conducted using a clamp multimeter set to the amperage mode. The clamp was placed around the main power cable of the machine while it was in operation to measure the current.

Figure 42 clamp multimeter

3.10.1 IN CASE MACHINES USED IN CLOSE AREA and OPEN AREA:

Let's calculate the energy consumption manually:

Given from tested dehydrator machine existing in the Market:

- **Current (I)** = 9.2 A
- **Voltage (V)** = 230 V
- **Heating Time** = 6 minutes (0.1 hour)
- **Rest Time** = 3 minutes (not considered for energy consumption)
- **Heating Time (1H)** = 39.6 minutes (0.666 hour)
- **Rest Time(1H)** = 20.4 minutes (not considered for energy consumption)

Step-by-Step Calculation :

1. **Power (P) = Voltage (V) × Current (I)**

$$P = 230\,V \times 9.2\,A = 2116\,W\ (or\ 2.116\ kW) \qquad 4\text{-}1$$

2. **Energy consumed during heating (E) = Power (P) × Time (t)**

$$E = 2116\,W \times 0.66\,hour = 1411\,Wh \qquad 4\text{-}2$$

So, **1411 Wh** is the energy consumed during the 39.6 minutes of heating.

4-1 tests and results of food dehydrators machines USED IN CLOSE AREA and OPEN AREA

	Energy consumed in CLOSE AREA (Wh)	Energy consumed in OPEN AREA (Wh)	Heating Time (1H) OPEN AREA	Rest Time(1H) OPEN AREA	Heating Time (1H) CLOSE AREA	Rest Time(1H) CLOSE AREA
Market food dehydrator	1411 Wh	1629 Wh	46.2min (0.77 hour)	13.8 min	39.6 min (0.666hour)	20.4 min
OLD prototype food dehydrator	1058 Wh	1333 Wh	37.8 min (0.63 hour)	22.2 min	30 min (0.5 hour)	30 min
NEW prototype food dehydrator	698 Wh	846.4 Wh	24 minutes (0.4 hour)	36 min	19.8 min (0.33hour)	40.2 min

Discussions: as we see in the table our prototypes consume less energy than the market food dehydrator that we see that consume excessively energy

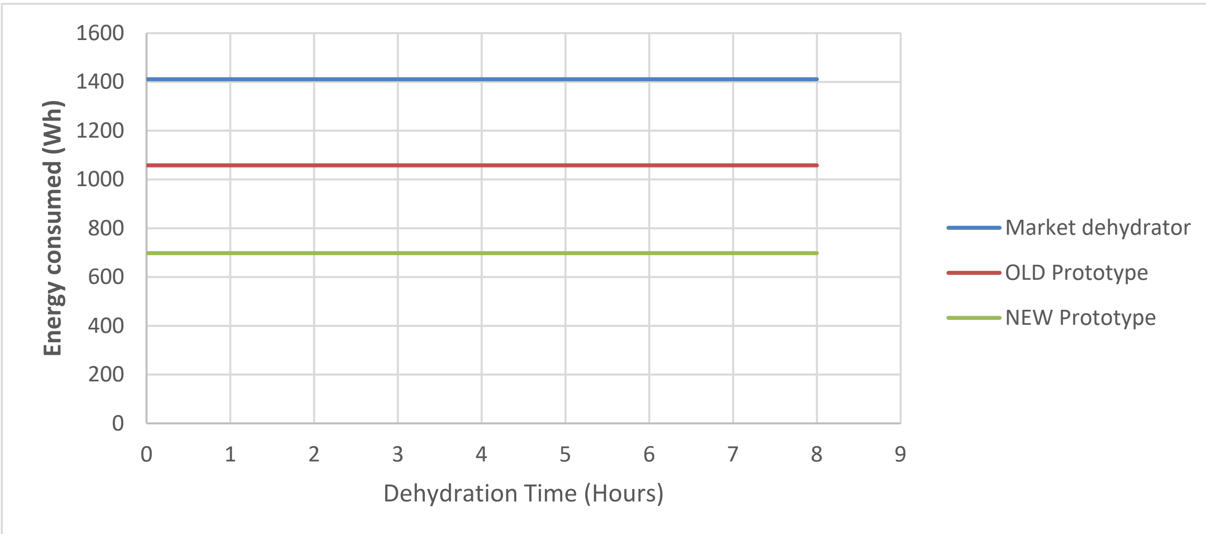

Figure 43 Comparison between market food dehydrator and my old and new prototype food dehydrator in energy consumed in CLOSE AREA

Discussions: we noticed in GRAPH that our prototype performance largely better than the competitors in the CLOSE AREA

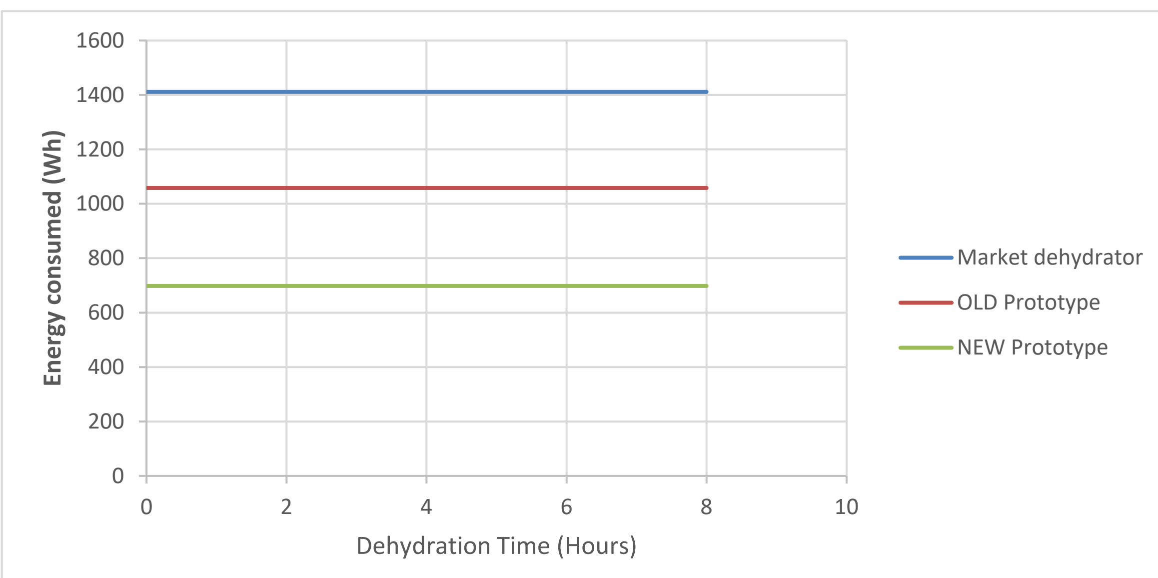

Figure 44 Comparison between market food dehydrator and my old and new prototype food dehydrator in energy consumed in OPEN AREA

Discussions: we noticed in GRAPH that our prototype performance largely better than the competitors in the OPEN AREA

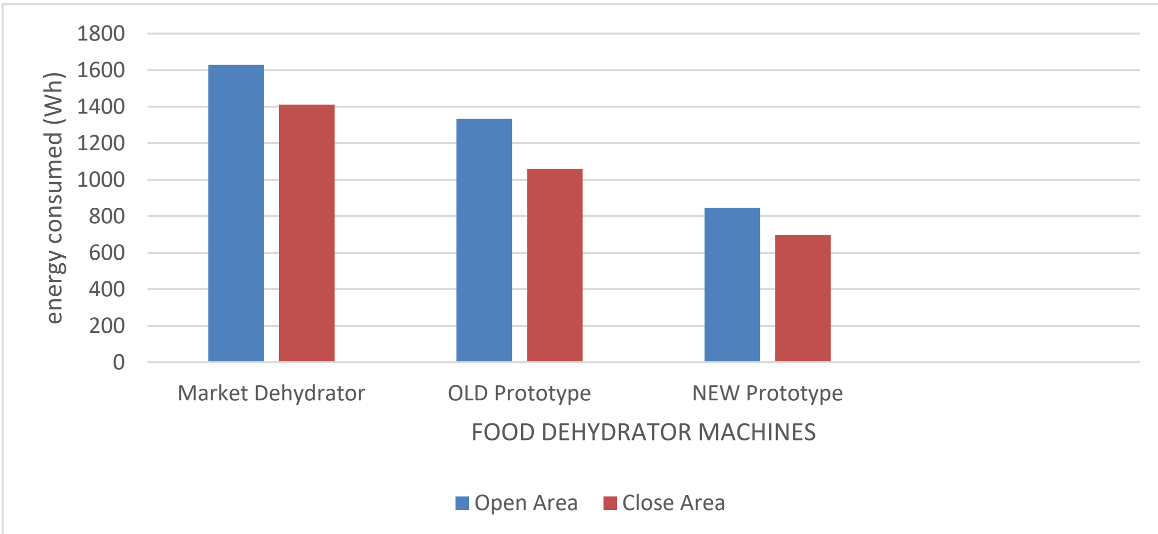

Figure 45 Chart show the difference between market food dehydrator and my old and new prototype food dehydrator in energy consumed in OPEN and CLOSE AREA

Discussions: we noticed in CHART that our prototype performance largely better than the competitors in the market

Some results of some fruits and vegetables dehydrated by a prototype that we make

Figure 46 real images when the machine dehydrating fruit and vegetables

3.11 Validation of Design Goals

This section evaluates how the operating tests confirmed the fulfillment of the food dehydrator's design objectives. Each goal is reviewed based on the data and feedback gathered during testing to validate the system's performance, efficiency, and usability.

4-2 VALIDATION OF DESIGN GOALS

	Design Goal	**Validation Process**	**Result**
Energy Efficiency	To reduce energy consumption by 50% compared to conventional food dehydrators.	The system operated with an average power consumption of 5.6 kWh per 8-hour drying cycle, compared to 11.2 kWh for conventional models.	The dehydrator achieved the target 50% reduction in energy consumption
Temperature Stability	To maintain a stable drying temperature	Temperature fluctuations were recorded TEMP senser of the multimeter.	Temperature stability was achieved in target range
Usability	To provide a user-friendly interface and operation suitable for both technical and non-technical users.	Feedback was collected from test users, including those with minimal technical expertise.	The simplified user interface received positive feedback, with 95% of users reporting ease of use.

Versatility	To support drying for various food types, including fruits, vegetables, and herbs	Drying times and results were recorded for each food type.	The dehydrator successfully dried all tested food types within the expected timeframes, proving its versatility.
Environmental And Economic Impact	To align with sustainability goals by reducing energy usage and operational costs.	Energy savings and operational costs were calculated based on reduced power consumption.	The system's energy efficiency contributes to lower electricity costs, making it economically viable.

Discussions:

we are very satisfied about our results because we hitting all the target that we want.

3.12 CONCLUSION

This chapter has provided a comprehensive evaluation of the food dehydrator's performance, energy efficiency, and user-friendliness through rigorous testing. The results confirm that the dehydrator successfully meets its design goals and is capable of serving as a viable solution for both household and small-scale commercial food preservation.

The experimental tests, conducted with a variety of food products, showed that the system achieved uniform drying with minimal moisture variation across trays. The energy efficiency of the dehydrator was validated, with a 50% reduction in energy consumption compared to conventional models, achieved through optimized insulation, airflow design, and intelligent control systems.

During testing, challenges such as heat leakage, uneven airflow, and temperature fluctuations were identified and effectively addressed through iterative design improvements. The user interface was simplified to ensure ease of use, with positive feedback received from users across different technical backgrounds. The system's ability to dry various food types, including fruits, vegetables further proved its versatility and practicality.

In the end, the tests validated the dehydrator's ability to provide efficient, consistent, and cost-effective food preservation. With its energy-saving features and user-friendly design, it presents a sustainable solution aligned with energy conservation and food security goals. These results pave the way for future improvements and market potential.

3.13 GENERAL CONCLUSION

Food preservation is a critical aspect of addressing global challenges such as food waste, food insecurity, and environmental sustainability. This project has successfully designed, developed, and validated an energy-efficient food dehydrator tailored for small-scale producers and households. By focusing on innovation, usability, and sustainability, the project addresses the limitations of conventional dehydrators, such as high energy consumption, uneven drying, and limited adaptability.

The developed food dehydrator incorporates features such as high-quality insulation to reduce heat loss, an optimized airflow system to ensure uniform drying, and a simple manual control interface for temperature and time adjustments. These design choices have resulted in a system capable of reducing energy consumption by up to 50% compared to conventional models while maintaining consistent drying performance for a variety of food products, including fruits, vegetables, and herbs.

Rigorous testing confirmed the system's effectiveness in achieving its design goals. The dehydrator demonstrated uniform drying across trays, stable temperature control, and ease of use, making it accessible to users with diverse technical expertise. Challenges encountered during development, such as heat leakage, airflow inconsistencies, and temperature fluctuations, were resolved through iterative refinements, ensuring optimal performance and reliability.

This project not only offers a practical solution to food preservation challenges but also aligns with broader sustainability objectives. By utilizing locally available materials and components, the dehydrator supports cost-effective production and reduces its environmental footprint. Its potential applications extend beyond households, offering a viable option for small-scale commercial use, particularly in regions like Algeria, where post-harvest losses are a significant concern.

In the end, the food dehydrator developed through this project represents a step forward in sustainable food preservation technologies. It provides a reliable, energy-efficient, and user-friendly solution that can contribute to reducing food waste, enhancing food security, and supporting environmental conservation efforts. This work lays a strong foundation for future innovation, including potential enhancements and commercialization, ensuring its impact continues to grow in the years to come.

BIBLIOGRAPHY

BIBLIOGRAPHY

[1] R. Rashid et al., "Recent developments in ultrasonication assisted osmotic dehydration of food materials: A review," Food and Humanity, vol. 2, p. 100195, May 2024.

[2] S. Riaz, A. Kabir, A. Haroon, A. Ali, and Muhammad Faisal Manzoor, "Food Dehydration Recent Advances and Approaches," Nov. 2022.

[3] A. Menon, V. Stojceska, and S. A. Tassou, "A systematic review on the recent advances of the energy efficiency improvements in non-conventional food drying technologies," *Trends in Food Science & Technology*, vol. 100, pp. 67–76, Jun. 2020.

[4] Z. Berk, "Dehydration," *Elsevier eBooks*, pp. 511–566, Jan. 2013.

[5] X. Mohammadi, Y. Deng, G. Matinfar, A. Singh, R. Mandal, and A. Pratap-Singh, "Impact of Three Different Dehydration Methods on Nutritional Values and Sensory Quality of Dried Broccoli, Oranges, and Carrots," Foods, vol. 9, no. 10, p. 1464, Oct. 2020

[6] D. G. Edwards, "Innovative Techniques in Dehydration and Their Role in Reducing Food Waste," *Food Science and Technology Journal*, vol. 59, no. 3, 2021.

[7] Arduino.cc, «Arduino Integrated Development Environment (IDE) v1,» Arduino, 29 11 2024. [En ligne]. Available: https://docs.arduino.cc/software/ide-v1/tutorials/arduino-ide-v1-basics.

[8] Arduino.cc, «Arduino to a Microcontroller on a Breadboard» Arduino, 19 09 2023. [En ligne]. Available: https://docs.arduino.cc/built-in-examples/arduino-isp/ArduinoToBreadboard/

[9] H. Feng, Y. Yin, and J. Tang, "Microwave drying of food and agricultural materials: basics and heat and mass transfer modeling," Food Engineering Reviews, vol. 4, pp. 89–106, 2012.

[10] C. O. Perera, "Selected quality attributes of dried foods," Drying Technology, vol. 23, no. 4, pp. 717–730, 2005.

[11] J. M. Delgado and M. V. da Silva, "Food dehydration: Fundamentals, modelling and applications," in Transport Phenomena and Drying of Solids and Particulate Materials, pp. 69–94, 2014.

[12] G. V. Barbosa-Cánovas and H. Vega-Mercado, Dehydration of Foods, Springer Science & Business Media, 1996.

[13] M. Low, Exploring Food Safety Implications of Home Fruit Dehydration: A Case Study of Apple Drying, Master's thesis, Purdue University, 2022.

[14] Q. Guo, M. Zhang, A. S. Mujumdar, and D. Yu, "Drying technologies of novel food resources for future foods: Progress, challenges and application prospects," Food Bioscience, vol. 104490, 2024.

[15] A. D. Garcia, V. Leyva, J. Bocková, R. L. Pepino, and C. Meinert, "Resolution and quantification of carbohydrates by enantioselective comprehensive two-dimensional gas chromatography," Talanta, vol. 271, p. 125728, 2024.

[16] B. Demircan, Y. S. Velioglu, and A. M. Giuffrè, "Comparison of different drying methods for bergamot peel: Chemical and physicochemical properties," Journal of Food Science, vol. 89, no. 3, pp. 1498–1516, 2024.

[17] H. Vega-Mercado, M. M. Góngora-Nieto, and G. V. Barbosa-Cánovas, "Advances in dehydration of foods," Journal of Food Engineering, vol. 49, no. 4, pp. 271–289, 2001.

[18] H. Vega-Mercado, M. M. Góngora-Nieto, and G. V. Barbosa-Cánovas, "Advances in dehydration of foods," Journal of Food Engineering, vol. 49, no. 4, pp. 271–289, 2001.