ISTANBUL AYDIN UNIVERSITY
ENGINEERING FACULTY
INTERNATIONAL JOURNAL OF FOOD ENGINEERING RESEARCH
(IJFER)

Year **6** Issue **1** - **April 2020**

International Journal of Food Engineering Research (IJFER) ISSN: **2149-5777**

April **2020** Year: **6** Number: **1**

Language
English

Publication Period
Published twice a year
April and October

http://ijfer.aydin.edu.tr/tr/editorler-kurulu/

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Printed by
Levent Baskı Merkezi - **Sertifika No:** 35983
Adres: Emniyetevler Mahallesi Yeniçeri Sokak No:6/A
4. Levent / İstanbul, Türkiye
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International Journal of Food Engineering Research (IJFER) is peer-reviewed journal which provides a platform for publication of original scientific research and applied practice studies. Positioned as a vehicle for academics and practitioners to share field research, the journal aims to appeal to both researchers and academicians.

Aims and Scope

International Journal of Food Engineering Research (IJFER) is an international, peer-reviewed journal devoted to the publication of high quality original studies and reviews concerning a broad and comprehensive view of fundamental and applied research in food science&technology and their related subjects as nutrition, agriculture, food safety, food originated diseases and economic aspects.

IJFER is an international periodical published twice a year (April and October). The journal is published in both print and electronic format.

From The Editor

International Journal of Food Engineering Research (IJFER) has been publishing by Istanbul Aydın University Faculty of Engineering Department of Food Engineering since 2015. The journal covers wide ranges of area such as Food Processing, Food Preservation, Food Microbiology, Food Chemistry, Biotechnology, Nanotechnology, Novel Technologies, Food Safety, Food Security, Food Quality and their related subjects as nutrition, food and health, agriculture, economic aspects and sustainability in food production.

Food Engineering is getting more and more attention because it is directly related to human health. While the food and drinks we eat help to protect our health, on the other hand, improper conditions during the conversion of the raw material to the product, the use of poor quality raw materials, and the employees not working under hygienic conditions can cause the food harmful to health. Our aim in this journal is to include the recent research and reviews on food and beverages from field to fork. Articles submitted to the journal are accepted for publication after being reviewed by expert referees.

In the following years, the journal will include scientific activities such as symposiums, congresses, conferences and workshops held in the field of food science and technology, and information about the books published in this field. We hope that the journal will be a good resource for engineers, experts, researchers and students working in the food industry.

Prof. Dr. Z. Dilek Heperkan
Editor

International Journal of Food Engineering Research (IJFER)

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DOI Numbers

Genel DOI: 10.17932/IAU.IJFER.2015.003
IJFER Nisan 2020 Cilt 6 Sayı 1 DOI: 10.17932/IAU.IJFER.2015.003/2020.601

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THE METHODS REDUCING OF FAT CONTENT IN MEAT AND MEAT PRODUCTS[1]

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ABSTRACT

In recent years, with the change in the level of awareness and expectations of consumers about healthy nutrition, research and development studies have accelerated in the food industry to formulate healthier food products with reduced fat content and functionally improved food products. Consumers demand healthier meat products that are low in fat, in general. On the other hand, consumers expect these meat products with altered formulations to taste, look and smell the same way as their traditionally counterparts. This review deals with the three major aspects to be considered in the context of reduction methods the fat content in meat and meat products. The first aspect involves removing of visible external fat. The second aspect involves changing of ruminants feedstuff. The third aspect involves using of fat replacer such as lean meats or low-fat meats, added water, carbohydrate-based substances, protein-based substitutes, vegetable oils in meat products.

Keywords: *Health, Low-fat, Fat replacer, Reduced-fat, Meat and meat products*

[1]Received: 17.01.2020 – Accepted: 15.02.2020

DOI:10.17932/IAU.IJFER.2015.003/ijfer_v06i1001

INTRODUCTION

Meat and meat products are important in the diet of developed countries. Their principal components, besides water, are proteins (high biological value, containing amino acids essential to human health) and fats (including saturated fatty acid, unsaturated fatty acid, cholesterol, triacylglycerol and phospholipids) with a substantial contribution of vitamins (mainly those of the B complex) and minerals (mainly iron and zinc) of a high degree of bioavailability **[1, 2, 3]**. Both meat and meat products can be modified by adding ingredients considered beneficial for health or by eliminating or reducing components that are considered harmful for health. In this way, a series of meat and meat products can be obtained which are considered "healthy" **[1]**.

Present day consumers are very much aware about nutrition and health. Thus they demand healthier meat products that are low in fat, cholesterol and calories. In meat products fat plays an important role in stabilizing meat emulsions, reducing cooking loss, improving water holding capacity and providing organoleptic quality (taste, odor, mouth feel, juiciness, hardness, etc.) **[4]**. However, high animal fat used in meat products provides higher amounts of saturated fatty acid and cholesterol **[5]**. Saturated fatty acid and cholesterol has been correlated with chronic disease events like cardiovascular diseases, cancer, type 2 diabetes, and others related to obesity **[6]**. The average composition, cholesterol content and calorific value of some representative types of meat and fat are shown in Table 1 **[7]**.

Besides serious health concerns of animal fat, oxidation of lipids and proteins being a major threat to meat quality. The onset of oxidative reactions in muscle foods during handling, processing and storage leads to undesirable sensory changes and deterioration of nutritive value **[8, 9]**. Therefore fat reduction has generally been seen as an important strategy to improve the fat content of foods and produce healthier products. This aspect is particularly relevant to the meat industry since some meat products contain high proportions of fat **[10, 11]**.

Table 1. Average composition, cholesterol content and calorific value of some representative types of meat and fat **[7]**

Type of Meat and Fat	Water (%)	Protein (%)	Fat (%)	Cholesterol (mg/100 g)	Energy Value (kcal/100 g)
Beef (muscle)	75.10	22.00	1.90	60.00	115
Veal (muscle)	76.40	21.30	0.81	70.00	101
Pork (muscle)	74.70	22.00	1.86	65.00	114
Mutton (fillet)	75.00	20.40	3.41	70.00	122
Chicken (average)	72.70	20.60	5.60	81.00	144
Turkey (average)	63.50	20.20	15.00	74.00	231
Lamb (intermuscular fat)	25.80	5.49	68.30	75.00	673
Beef (intermuscular fat)	20.20	8.20	70.90	99.00	710
Pork (intermuscular fat)	18.00	4.70	76.70	93.00	749

Besides serious health concerns of animal fat, oxidation of lipids and proteins being a major threat to meat quality. The onset of oxidative reactions in muscle foods during handling, processing and storage leads to undesirable sensory changes and deterioration of nutritive value **[8, 9]**. Therefore fat reduction has generally been seen as an important strategy to improve the fat content of foods and produce healthier products. This aspect is particularly relevant to the meat industry since some meat products contain high proportions of fat **[10, 11]**.

The first step in developing healthy meat products is to reduce the high-fat content of meat products **[12]**. Some processed meat products contain up to 20-30% fat content. However, the reduction of fat content results in inferior product quality in terms of technological and sensory attributes, which affects the marketability and consumer acceptance of low-fat meat products **[13]**. Hence, the meat industry is facing the problem to produce low-fat processed meat products with desired quality attributes **[14]**.

In this review, studies on the methods used to reduce the amount of fat in meat and meat products have been analyzed based on the literature.

There are basically 3 ways to reduce the fat content in meat and meat products: (1) removing of visible external fat, (2) changing of ruminants feedstuff, and/or (3) using of fat replacer in meat products **[15]**.

Removing of Visible External Fat

The easiest way to reduce fat in the diet is to keep the amount of fat in the meat as low as possible and to consume lean meat with visible external fats in meat can be removed by trimming process. This process highly reduces the total fat content of the meat. The first trimming process can be applied to the internal and external fats in the carcass, and then the trimming process can be applied to the cut parts where necessary **[15]**. Trimming of subcutaneous fat could be effective for reducing both dietary cholesterol and fat (and calories) **[16]**. Trimming of excess fat from carcass even though highly reduces the fat content of overfat carcasses, this is short term solution for providing low-fat products **[17]**.

Changing of Ruminants Feedstuff

Changes in the diet of ruminants can lead to major differences in the fat content and fatty acid profile of edible tissues **[15]**. One way to increase unsaturated fat in the human diet without giving up meat is to feed meat-producing animals with feeds that contain high levels of unsaturated fats. Such a modification in the diet of animals can increase the level of unsaturated fatty acids and reduce the amount of saturated fatty acids **[18]**. The fat composition of meats is necessary to produce healthier meat with higher monounsaturated and polyunsaturated fatty acids than saturated fatty acids, and to establish an appropriate balance between n-6 and n-3 polyunsaturated fatty acids **[15]**.

Monounsaturated fatty acid content in meat can be enhanced by increasing these fatty acids in the animal diet. Feeding strategies involving plant (vegetable oils, n-3 polyunsaturated fatty acid-rich plants, forages) and marine sources (fish or algae) have been successfully used to significantly increase polyunsaturated fatty acids **[3]**. Dietary supplementation such as α-linoleic acid, conjugated linoleic acid, docosahexaenoic acid, eicosapentaenoic acid has been used to enrich chicken, pork, beef and lamb **[19]**. In another study found that feeding pigs diets containing 20% canola oil (60-65% oleic acid) decreased the level of saturated fatty acids in muscle tissue and adipose tissue by 19% and 25%, respectively **[20]**.

Using of Fat Replacer in Meat Products

Normal fat contents of meat products are shown in Table 2 **[21]**. Low-fat meat products have been rejected by the consumers since they were considered less juicy, firmer, more rubbery, darker in color and overall less acceptable than traditional meat products **[22]**. On the other hand, consumers hope that these low-fat meat products with altered formulations to taste, look and smell in the same way as their traditionally formulated and processed meat products. In this respect, manufacturers have introduced several modifications. These modifications include the use of fat replacers such as lean meats or low-fat meats, added water, carbohydrate-based substances, protein-based substitutes, and vegetable oils. **[15, 22, 23]**.

Table 2. Normal fat content of meat products **[21]**

Meat Product	Fat Content (%)
Frankfurter	20-30
Bologna	20-30
Fresh pork sausage	30-50
Nugget	20-25
Liver sausage	30-45
Salami	30-50
Beef patty	20-30
Ham	<10

Lean meats or low-fat meats

Lean meats or low-fat meats can be used instead of fat in the formulation to reduce the fat content of meat products. However, this process does not cause a reduction in the amount of cholesterol in the product. In addition, while the use of lean meat and low-fat meat in meat product formulations is not economically preferred because it increases the cost; it is not preferred technologically because it creates harder and drier products compared to standard products **[15]**.

Added water

Alternative methods have been considered to ensure that low-fat meat products are at an acceptable level in terms of taste, and it has been reported that adding water instead of fat can be one of the possible solutions **[15]**. Water can be used as a substitute for fat in sausages and other heat treated meat products. The addition of water causes changes in properties such as structure, softness and hardness in meat products with reduced fat **[24, 25]**. The use of water instead of fat can cause the product to be too hard and excessive water loss from the product. In addition, the addition of water affects the microbial shelf life of the product and the product flavor **[26, 27]**. In low-fat meat products, with different additives with water, sensory it is possible to increase the quality characteristics. Juiciness and softness can be improved by using agents that keep moisture in the product **[28]**.

In the study carried out, sweet potato powder and water were added as fat substitute in low-fat pork patties. Low-fat pork patties were developed by replacing the added fat with combinations of sweet potato powder and chilled water. Three different levels of sweet potato powder/chilled water 0.5/9.5%, 1.0/9.0%, and 1.5/8.5% were compared with a control containing 10% animal fat. Results concluded that low-fat pork patties with acceptable sensory attributes, improved cooking yield and textural attributes can be successfully developed with the incorporation of a combination of 1.0% sweet potato powder and 9.0% chilled water **[29]**.

Carbohydrate based substances

Dietary fibers, cellulose, starch, maltodextrin, dextrin, hydrocolloids, gums, etc. are often used as carbohydrate-based fat substitutes. Carbohydrates are formed of polymers of repetition sugar and sugar derivatives which can bind water and increase viscosity or gel **[30]**. Starches and fibers of various including corn starch, rice starch, potato starch, and tapioca starch can be efficiently used in meat formulations. Starch granules swell when hydrated, then gelatinize when heated. They may increase in viscosity or gel as they are cooled. Fibers can add bulk, assisting in hydration and contributing to mouth feel in low-fat meat products.

Carbohydrate-based fat replacers mimic fat by stabilizing the added water in a gel-like matrix that can release the water in a way similar to fat release **[12]**. Gums such as carrageenan, alginate, xanthan, locust bean and guar gum are also frequently used as carbohydrate-based fat replacers **[15]**.

In the study carried out investigated that guar-xanthan gum mixture as a partial fat replacer in meat emulsions. Partial replacement of fat with guar-xanthan gum resulted in higher emulsion stability and cooking yield but lower penetration force. In addition, the guar-xanthan gum mixture improved the physicochemical and oxidative quality of low-fat meat emulsions than the control formulations **[31]**.

In another study carried out, the technological properties were evaluated for low-fat meat emulsions containing various levels of prebiotic fibers (inulin, fructo-oligosaccharide, polydextrose, and resistant starch) as fat substitutes. The fiber addition delayed the aggregation of globular myosin heads; thus, the gelation process occurred at higher temperatures. The microscopy assays showed porous structure in the formulations containing prebiotic fiber and more compact and denser structures in the control formulations **[32]**.

Protein-based substances

Blood plasma, egg protein, caseinate, skimmed milk powder, soy protein flour/concentrate/isolate, whey protein, wheat gluten, etc. are often used as protein-based fat substitutes. Vegetable and animal originated proteins are used in various meat products in terms of emulsion stability due to their fat and water binding properties **[15]**. The three dimensional structure of proteins can be changed by pH, heat or enzymatic denaturation and providing to behave more like fat **[33]**. Denaturation can change the textural, gel forming and water holding capacity particularly of vegetable based proteins such as soy, wheat, pea, and peanut **[17]**. Whey, collagen and soy protein as protein-based fat replacers are often used in meat industry **[12]**.

In the study carried out investigated that plasma protein and soy fiber contents effect on bologna sausage properties as influenced by fat level. Plasma protein and soy fiber contents favored the formation of harder, chewier structures with improved fat and water binding properties. Fat reduction decreased textural properties and increased weight loss. Plasma protein influenced binding and textural properties more than soy fiber and was, therefore, thought best to limit the effect of fat reduction **[34]**.

In another study carried out, whey powder at levels of 0%, 2% and 4% was added to beef meatballs formulated with 5%, 10% and 20% fat levels. Addition of 2% or 4% whey protein significantly increased cooking yield regardless of the fat level. Both fat level and whey protein level significantly affected fat retention values of meatballs **[35]**.

Vegetable oils

The general nutritional profile of meat products is influenced by the ratio of n-6/n-3 fatty acids, polyunsaturated fatty acids/monounsaturated fatty acids content. This has led to the use of fat source with healthier fatty acid profile, instead of animal fat, for improving of health meat products. Thus, vegetable oils have been studied in place of animal fat and a large amounts of saturated fatty acids have been substituted with monounsaturated fatty acid/polyunsaturated fatty acid **[36, 37]**.

In the study carried out, into salami products, found that the partial substitution of pork backfat by extra virgin olive oil did not significantly influence the chemical, physical, and sensory characteristics of the products, with the exception of water activity and firmness. The addition of the extra virgin olive oil, which is rich in unsaturated fatty acids, did not reduce the shelf life in terms of lipid oxidation, perhaps because of the antioxidant effect of both polyphenols and tocopherols **[38]**.

Table 3 summarized the use of various fat replacer substitutes obtained from different sources in different meat products and their effects on meat products.

Table 3. Articles about meat and meat products with fat replacer

Meat Product	Fat Replacers	Impact on Product	Reference
Chicken patties	Cashew apple fiber (*Anacardium occidentale* L.)	Increased the cooking yield Did not negatively affect shortening and shear force values Appearance, texture, flavor, juiciness, overall impression values were not different from control	**[39]**
Beef sausage	Hazelnut oil Hazelnut powder	Decreased the saturated fats and increased the unsaturated fats Equivalent texture, sensory, technological quality to standard	**[40]**
Goshtaba (traditional meat product of India)	Apple pomace powder	Decreased the hardness, cohesiveness, gumminess, chewiness Increased the springiness	**[41]**
Fermented sausage (Sucuk)	Pre-emulsified olive oil	Decreased the cholesterol content about 41.3%	**[42]**
Beef meatball	Adzuki beans (*Vigna angularis*) flour	Increased the cooking yield and moisture content Increased the hardness, chewiness Decreased the fat and calorie contents	**[43]**
Bologna type sausage	Pork skin Green banana flour	Decreased the cooking loss Increased the emulsion stability	**[13]**

Frankfurter type sausage	Citrus fibre Soy protein concentrate	Addition of soy protein concentrate increased the water holding capacity and cooking losses Addition of citrus fiber increased the water holding capacity and decreased the cooking losses	**[44]**
Frankfurter type sausage	Inter-esterified palm, cotton seed and olive oils	Improved the nutrient quality, due to changes in fatty acid profile	**[45]**
Hamburger	Soy flour, split-pea flour and wheat starch	Soy flour in combination with starch leads to increase in cooking yield and addition of split-pea flour in mixed formula decreases shrinkage while improving textural properties.	**[46]**
Ostrich meat patties	Modified corn starch, soya isolate and water	Decreased the saturated fatty acids and increased the unsaturated fatty acids	**[47]**

CONCLUSION

Meat and meat products can be modified by adding ingredients considered beneficial for health or by eliminating or reducing components that are considered harmful for health. The add of these ingredients considered beneficial and the eliminate and reduce the ingredients considered harmful in meat products offers processors the opportunity to improve the nutritional and health qualities of their products. Although the demand is present for low-fat meat products, formulating a low-fat meat product equal in quality to its full-fat counterpart is a difficult task. The key ingredient in a low-fat meat formulation is the fat replacer or combination of fat replacers chosen. Good fat replacers have must a particle size and water holding capacity that mimics the mouth feel and juiciness of real fat. The final product should be equal to the full-fat product in all aspects, except for fat.

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THE ANTIOXIDANT ACTIVITY OF *APIUM GRAVEOLENS*[1]

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ABSTRACT

Plants are an important source of natural active products that differ depending on the chemical components they contain. Since extracts and phytochemicals isolated from plants show biological activity *in vitro* and *in vivo*, today plants are used as alternative treatment sources. *Apium graveolens* (celery) has powerful antioxidant properties to remove free radicals due to compounds such as coumarin, alkaloids, steroids, phenols, essential oils, sesquiterpene alcohols, caffeic acid, p-coumaric acid, ferulic acid, apigenin, luteolin, tannin, saponin and kaempferol. Celery with different compounds and different concentrations has various healing effects. The aim of this study was to review the antioxidant activity of celery.

Keywords: *Apium graveolens, Celery, Antioxidant activity*

[1]Received: 27.12.2019 – Accepted: 19.01.2020
DOI: 10.17932/IAU.IJFER.2015.003/ijfer_v06i1002

INTRODUCTION

The use of medicinal plants to treat illness has been common since ancient times. Many studies have shown the positive effects of various herbs and different parts of medicinal plants on cancer, infectious diseases, diabetes, atherosclerosis **[1, 2, 3]**. Phenolic and alkaloid compounds in plants and their effects such as antioxidant effects have been investigated in many studies such as cancer **[4, 5, 6]** diabetes **[7, 8]**, liver disorders **[3]**, coronary heart diseases **[9, 10].** Today herbal drugs are used as an alternative to chemical drugs due to their low side effects.

Celery (*Apium graveolens* L) is a plant from the apiaceae family, and is one of the annual or perennial plants that grow throughout Europe, Africa and Asia **[11].** Celery seeds are used as a condiment in the flavoring of food products possessing a characteristic aroma and pungent taste. There are a number of phthalide derivatives that give the celery essential oil a characteristic odor **[12].**

Celery (*Apium graveolens*) is a medicinal plant in traditional medicine with numerous health benefits. Celery can prevent arthritis, rheumatism, gout, urinary tract inflammation, and specifically rheumatoid arthritis with mental depression **[13].** Celery, because of compounds such as caffeic acid, p-coumaric acid, ferulic acid, apigenin, luteolin, tannin, saponin, and kaempferol, has powerful antioxidant characteristics, to remove free radicals. Antioxidants with radical scavenging capacity are thought to have a potential protective effect against free radical damage. These biomolecules inhibit oxidative reactions that prevent the formation of coronary and vascular diseases and tumors **[11, 14].** This oxidative damage is the result of free radical action on, for instance, lipids or DNA. However, the commonly used synthetic antioxidants such as butylated hydroxyanisole (BHA) and butylated hydroxyl toluene (BHT), are limited by law because of their toxic effects and carcinogenicity **[15].** The elimination of synthetic antioxidants in food applications has provided further impetus to explore the source of natural antioxidants. The objective of the present review is to highlight the antioxidant effects of *Apium graveolens.*

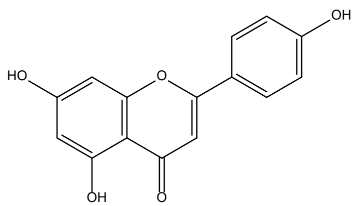
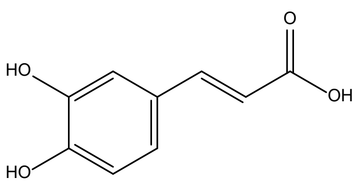
Phytochemical Constituents

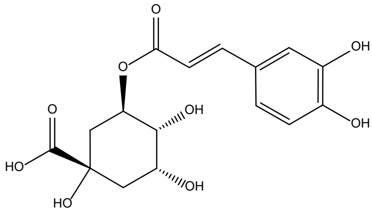
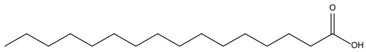
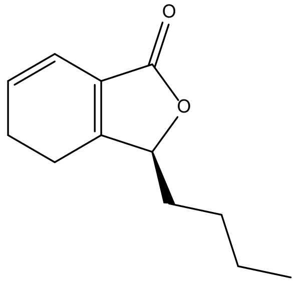
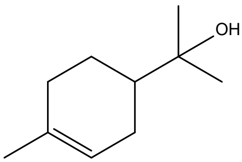
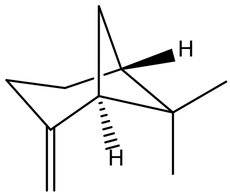
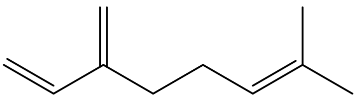
The preliminary phytochemical analysis revealed the presence of carbohydrates, flavonoids, alkaloids, steroids, and glycosides in the methanolic extract of seeds of *Apium graveolens* **[9].** Seeds included flavonoids, volatile oils, coumarins and furanocoumarins. Coumarins contained celerin, bergapten, apiumoside, apiumetin, apigravrin, osthenol, isopimpinellin, isoimperatorin, celereoside, and 5 and 8-hydroxy methoxypsoralen. Flavonoid included apiin, apigenin, isoquercitrin **[13, 16].** The phenolic concentration in different extracts (methanol, ethanol, water) varied significantly. Among the methanol extract of the seeds, *Apium graveolens* methanolic extract had the highest phenolic concentration (73.1 ± 1.23 mg GAE/100g) **[17].** Volatile oils included limonene (60%) and selenine (10–15%), and various sesquiterpene alcohols (1– 3%), e.g. α-eudesmol and ß-eudesmol, santalol. Also, celery includes linoleic, myristic, myristoleic, oleic, palmitic, palmitoleic, petroselinic and stearic acid **[13].** The main chemical constituents present in each part of the plant are as follows: The roots contain falcarinol, falcarindiol, panaxidol, and polyacetylene 8-O-methylfalcarindiol **[18, 19].** The stem contains pectic polysaccharide (apiuman) containing d-galacturonic acid, 1-rhamnose, 1-arabinose, and d-galactose **[20].** Leaves contain 1-dodecanol, 9-octadecene-12-ynoic acid, methyl ester and tetradecene-1-ol acetate **[21].** Celery seed contains caffeic acid, chlorogenic acid, apigenin, rutaretin, ocimene, bergapten, and isopimpinellin **[22].** The seed oil is composed of palmitic acid, stearic acid, oleic acid, linoleic acid, petroselinic acid, d-limonene, selinene, terpineol, and santalol **[23].**

Table 1. Essential oil composition of celery (*Apium graveolens*) seed. **[9]**

Components	Percentage (%)
D-limonene	57.7
Myrcene	18.7
4-terpineol	8.6
ß-selinene	8.1
ß-pinene	2.4
ß- caryophyllene	0.5
Carnone	0.3
Trans-limonene oxide	0.3
α-terpinolene	0.3
α-selinene	0.2
Trans-3-butylidenephthalide	0.1
α-muuroloene	0.1
Cis-limonene oxide	0.1
Linalool	0.1
α-pinene	0.1
Trans-ocimene	0.1

Table 2. The chemical constituent of the celery (*Apium graveolens)* seed having antioxidant characteristic

Group of Chemicals	Chemical Constituents	Structure	References
Glycosides	Apigenin	 apigenin	**[24, 25]**
Organic acid	Caffeic acid	 caffeic acid	**[26]**

Organic acid ester	Chlorogenic acid	 Chlorogenic acid	[27]
Fatty acids	Palmitic acid	 Palmitic acid	[28, 29]
Essential oil	Sedanolide	 sedanenolide	[30]
Essential oil	Terpineol (2-(4-Methylcyclohex-3-en-1-yl) propan-2-ol)	 2-(4-Methylcyclohex-3-en-1-yl)propan-2-ol	[31]
Essential oil	ß-pinene	 ß-pinene	[32]
Essential oil	ß-myrcene	 ß-myrcene	[33]

Antioxidant Effect

In the study by Kolarovic et al. **[34]** of the antioxidant activities [as measured by the content of reduced glutathione (GSH) and ferric reducing antioxidant power (FRAP)] of celery and parsley leaf and root juices in rats treated with doxorubicin, was investigated**.** Celery root juice increased antioxidative capacity and the total antioxidative capacity (TAOC) in liver homogenate. Celery leaf juice increased GSH content but did not increase FRAP in liver homogenate. Study results show that celery increases antioxidant activity.

The study by Al Sa'aidi et al. **[35]** of antioxidant activity of n-butanol celery extract (*Apium graveolens*) seed in streptozotocin-induced diabetic rats was investigated**.** Thirty-two mature male rats were divided into four groups as diabetic and non-diabetic. Rats ≥ 200 mg/dl of blood glucose were used as diabetic. Diabetic groups were drenched with drinking water, n-butanol extract (60 mg/kg, b.w.), or injected with insulin (4 IU/animal), respectively for 21 days. Blood and liver subcellular fluid were obtained for the evaluation of alanine aminotransferease (ALT), Aspartate aminotransferase (AST), catalase (CAT), Superoxide dismutase (SOD), Glutathione (GSH) -transferase and -reductase enzymes and Malondialdehyde (MDA), glutathione concentrations. N-butanol extract of celery seed or insulin therapy moderated blood glucose within a normal range, enhanced body weight gain and normalized the activities of all antioxidant enzymes. Study results show that n-butanol extract of celery seed has a potent role in ameliorating stressful complications accompanied by diabetes mellitus.

In the study by Li et al. **[24]** *in vitro* and *in vivo* antioxidant activity of ethanol extract of celery leaf was investigated**.** Superoxide dismutase (SOD), glutathione peroxidase (GSH-Px) and catalase and total antioxidant capacity (TAOC) activities were measured in serum, brain, heart, liver, and kidneys. As a result, celery has a radical scavenging effect and SOD, GSH-Px CAT have been shown to significantly increase the activity.

Yıldız et al. **[36]** identified the essential antioxidant compounds and measured the total antioxidant capacity with CUPRAC (cupric ion reducing antioxidant capacity) and ABTS spectrophotometric methods**.** The CUPRAC spectrophotometric method of TAC assay using copper(II)-neocuproine (2,9-dimethyl-1,10-phenanthroline) was developed. Antioxidant compounds in celery plant extracted by HPLC were analyzed on one column of C18. Study results show that methanolic and ethanolic extract of celery leaves have antioxidant properties.

Yao et al. **[37]** analyzed the phenolic compound composition and antioxidant activities of 11 celery varieties**.** The contents of total phenolics were measured using a Folin–Ciocalteu assay and the total antioxidant capacity was measured with the 1,1-diphenyl-2-picrylhydrazyl radical and 2,2-azino-bis (3-ethylbenzothiazoline-6-sulfonic acid) methods. The most common flavonoid in celery was apigenin and phenolic acid was p-coumaric acid. The investigated celery varieties had high levels of phenolics and exhibited high antioxidant capacity. Antioxidant activity was found to be proportional to total flavonoids, total phenolic acids or total phenolics.

In the study by Nagella et al. **[21]** essential oil composition of celery leaf, immunotoxicity effects and antioxidant activity were investigated**.** Essential oils contained in *A. graveolens* leaves were found using gas chromatography and mass spectroscopy (GC-MS). The essential oil from the *A. graveolens* leaves was investigated for scavenging of the 1,1-diphenyl-2-picrylhydrazyl (DPPH) radical activity. The results showed that the essential oil from the *A. graveolens* has potential as a natural antioxidant and thus inhibit the unwanted oxidation process.

Shanmugapriya and Ushadevi **[38]** studied the antibacterial and antioxidant activity of Methanol, Diethyl ether and aqueous extracts of *Apium graveolens* seeds**.** The antioxidant activity of *A.graveolens* seed extracts was carried out 2, 2-Diphenyl-1- picrylhydrazyl (DPPH) assay method. The methanol extract showed the highest inhibition against bacterial pathogens and higher antioxidant activity than that of standard Gallic acid. The study result showed that A.graveolens seed extract exhibiting enormous significance in therapeutic aspects.

Ud Din et al. **[39]** evaluated the phytochemical screenings, antioxidant activity and antimicrobial assay of *Apium graveolens* L**.** The total phenolic content was slightly higher in methanolic fraction (63.46 ± 12.00 mg GAE/g) than ethanol (36.60 ± 12.28 mg GAE/g) and hexane fractions (34.86 ± 6.96 mg GAE/g). The flavonoid content was high in methanolic extract (56.95 ± 7.14 mg Quercetin/g). Ethanol extract showed good antimicrobial activity. Antioxidant activities of extracts were measured according to DPPH, ABTS and FRAP assays. Antioxidant activity assayed by FRAP was higher in methanolic fraction (12.48 ± 1.06 mmole of FeSO4 equivalent/litre of extract) compared with other extracts.

The study by Hassanen et al. **[40]** the constituents of the essential oil, antioxidant and antimicrobial activity of celery (*Apium graveolens*) was investigated**.** The chemical composition of the essential oils obtained by hydrodistillation was analyzed by GC/MS. The antioxidant activities of volatile oils extracted from the celery were assessed by the Rancimat apparatus and DPPH. Study results show that all essential oils under study at various concentrations exhibited antioxidant activity.

Ksouda et al. **[41]** investigated 25 Tunisian plant species of 13 families based on their oil and total phenolic contents**.** The phenolic content of seed methanolic extracts, measured by Folin–Ciocalteu assay (490 ± 60 mg GAE/100 g Dry Weight). In the ABTS assay, the antioxidant activity value was 1000 ± 150 mg TEAC/100 g DW. In the DPPH assay, the antioxidant activity value of *Apium graveolens* was 480 ± 30 (mg TEAC/100 g DW). The results showed that the seeds of *Apium graveolens* had high oil content, interesting fatty acid profiles and its methanolic extracts displayed high antioxidant capacities.

Jung et al. **[12]** the leaves of *A. graveolens* extracted with methanol and partitioned with water, ethyl acetate and butanol**.** The phenolic content of the extracts was determined by Folin-Coicalteu method. Antioxidant capacity was measured by using α, α-diphenyl-β-picrylhydrazyl (DPPH), β-carotene-linoleate, reducing power, metal chelating effects and phosphomolybdenum method. The phenolic content of the extracts was expressed as gallic acid equivalents and was found to be highest in methanol (51.09 mg/g). At a concentration of 250 g/ml, methanol extract has the highest free radical scavenging activity and reducing power. The study result showed that celery leaf vegetable is a good source of antioxidants due to its phenolic richness.

Han et al. **[42]** investigated the effect of digestion on the phenolic compounds and antioxidant activity of celery leaf**.** 13 phenolic chemicals were discriminated by HPLC-MS, and content of phenolic and the antioxidant capacity were evaluated after digestion in vitro. The extraction of celery leaf decreased lipid peroxidation and reactive oxygen species level. It was also found that celery leaf increased antioxidant activity of liver, spleen and thymus of mice treated with Dexamethasone.

In the study by Popovic et al. **[43]** the potential protective action of the ether, chloroform, ethyl acetate, n-butanol, and water extracts was assessed by the corresponding *in vitro* and *in vivo* tests**.** In the in vitro experiments crude methanol extracts were tested as potential scavengers of free OH• and DPPH• radicals, as well as inhibitors of liposomal peroxidation (LPx). The results showed that both the extracts of root and leaves are good scavengers of OH• and DPPH• radicals. *In vivo* experiments were concerned with antioxidant systems (activities of GSHPx, GSHR, Px, CAT, SOD, GSH content and intensity of LPx) in liver homogenate and blood of mice after their treatment with extracts of celery leaves, or in combination with CCl_4. On the basis of the results obtained n-butanol extract showed the highest protective effect.

Table 3. Antioxidant Activity of Celery.

Type of extract	Used Parts	Model	Results	References
Aqueous extract	Root and leaves	*In vivo*	- Celery root juice increased antioxidative capacity, - Celery leaf juice increased GSH content	**[34]**
Aqueous extract	Seed	*In vivo*	- n-Butanol extract of celery seed normalized the activities of all antioxidant enzymes	**[35]**
Ethanolic extract	Leaves	*In vivo* and *In vitro*	- Scavenging activity on MDA and LPF. - Enhanced the activities of SOD, GSH-Px, and CAT	**[24]**
Methanolic and ethanolic extracts	Leaves	*In vitro*	Increased total antioxidant capacity	**[36]**
Ethanolic extract	All of the parts	*In vitro*	Excellent free radical scavenging activities	**[37]**
—	Leaves	*In vitro*	Has potential as a natural antioxidant and thus inhibits unwanted oxidation process	**[21]**
Methanolic, diethyl ether and aqueous extracts	Seeds	*In vitro*	Methanol extract showed the highest antioxidant activity	**[38]**
Methanolic, ethanol and hexane extracts	—	*In vitro*	Antioxidant activity was observed	**[39]**

Aqueous extract	Seeds	*In vitro*	Exhibited antioxidant activity	**[40]**
Methanolic extract	Seeds	*In vitro*	Extract exhibited high antioxidant activity	**[41]**
Methanol, water, ethyl acetate and butanol extract	Leaves	*In vitro*	The antioxidant and free radical scavenging activities of the extracts assayed through DPPH and reducing power were found to be highest with methanol	**[12]**
Water extract	Leaves	*In vitro* and *In vivo*	The extraction of celery leaf decreased lipid peroxidation and reactive oxygen species level, and elevated the antioxidant activities	**[42]**
Methanol, ethyl acetate, butanol and water extract	Root and leaves	*In vitro* and *In vivo*	Root and leaves are good scavengers of OH• and DPPH• radicals and reduce liposomal peroxidation intensity in liposomes	**[43]**

CONCLUSION

This study investigated the properties of celery leaves and seeds. Celery is a commercially important seed spice, valued for its medicinal properties. Celery because of compounds such as coumarin, apigenin, luteolin, tannin, kaempferol has powerful antioxidant characteristics. The plant composition and medicinal properties lead to need for further and more research about other useful and unknown properties of it, so used as plant-derived medicine to treat diseases.

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FUNDAMENTAL DRYING TECHNIQUES APPLIED IN FOOD SCIENCE AND TECHNOLOGY[1]

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ABSTRACT

Fresh food and food products with high water activity are easily degradable. Drying is one of the most fundamental preservation techniques used to improve the shelf-life of food. However, drying techniques used for the removal of excess water from food need to be efficient, economic, and able to create dried food with high-quality. The drying process needs to protect nutrient compounds, aroma, texture, and appearance of products. However, due to the emission of hot exhaust gases from the conventional dryer to the environment, and according to the demand for the application of green energy, the use of non-conventional dryer with higher efficiency and faster drying is considered in a recent review. This paper reviews the mechanisms, advantages, and applications of some conventional and non-conventional drying techniques in the food industry. These include hot air drying, spray drying, electrohydrodynamic drying, infrared drying, radio frequency drying and microwave drying.

***Keywords**: Spray drying, Radio frequency drying, Electrohydrodynamic drying, Infrared drying*

[1]Received: 11.01.2020 – Accepted: 07.02.2020

DOI: 10.17932/IAU.IJFER.2015.003/ijfer_v06i1003

INTRODUCTION

Drying is an ancient technique which is used for hundreds of years to protect food products from various microbial spoilage and chemical deterioration it is aimed to extend the shelf-life of foodstuff. Drying technology is an indispensable unit operation for the large-scale preservation of foodstuff. Also, it has a vast application to create new products with various shapes (such as powder, flake, granules, etc.) in the food manufacturing sector. The goal of drying is to decrease moisture content and water activity of food products to the desired level by thermal or non-thermal processes **[1, 2]**. Furthermore, drying decreases packaging, transportation, handling costs. The different benefits of the drying process were shown in Figure 1.

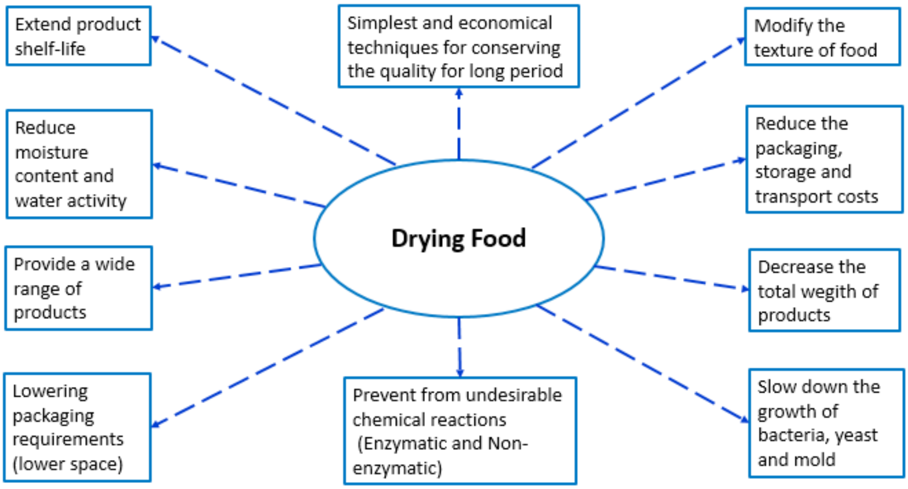

Figure 1. Application of drying technology in the food industry.

Water as the main component of foodstuff has a crucial role in the oxidation of fats and lipids and the growth of microorganisms in food with high moisture content and high-water activity. Also, the amount of water in dried products has an important effect on the texture and flavor of dried food. Exposing a foodstuff to the environment leads to the transfer of water between the food and environment due to the tendency of food to reach the most stable condition according to the equilibrium state **[3]**. Drying is the most simple and economical method and used to decrease the water activity and moisture content of the material to decrease physical and chemical changes of food **[4]**. The drying technology can be classified into conventional and non-conventional drying methods. Many conventional drying methods have lower operating costs, but they emit hot exhaust gases to the environment. Therefore, nowadays many non-conventional drying methods are taken into consideration.

Sun-drying is a conventional drying method that directly exposed food to open sunlight and wind. However, it depends on the weather condition and also has a high risk of contamination. The use of a solar dryer to change solar energy to heat to decrease the water content of food can be a good alternative for sun-drying **[5]**. Another traditional and commonly used drying technique is hot air drying (HAD) which can be done under natural or forced convection. More than 85% of industrial dryers use hot air for drying materials **[6]**. Hot air drying was used by many authors in the drying of different foodstuffs such as carrot, pumpkin, and apple at the air temperature of 50, 60, and 70°C **[7]**, mango slice at 60°C **[8]**, red carrots at 60°C, square, circle and triangle apple chips at 110, 115, and 120°C **[1]**, Lentil seed at 45, 50, 55, and 60°C **[9]**, and persimmon at 45, 50, 55, 60, and 65°C **[10]**.

Another conventional drying method is spray drying which is applied to drying liquid food. In this method, a liquid feed is injected into the atomizing units which convert it to the fine droplets, and then spray these fine droplets to the hot airflow. Consequently, the rapid evaporation of water produces dried particles and due to short drying time, it is suitable for drying the food with high heat sensitivity. Also, spray drying can use to encapsulate various bioactive compounds such as nutrients, vitamins, probiotics, antioxidants, enzymes, and aroma compounds. Many examples of utilization of spray dryer can be cited such as encapsulation of carotenoids **[11, 12, 13, 14]**, lycopene **[15]**, β-carotene **[16]**, guava extract **[17]**, curcumin **[18]**, fish oil **[19]**, *Bifidobacterium infantis* and *Lactobacillus plantarum* **[20]**, *L. rhamnosus* GG **[21]**.

Infrared (IR) drying is a non-conventional drying process that uses IR rays for drying food products. The penetration of IR rays into a depth of moist food can increase its temperature, moisture diffusion and water evaporation from samples. Many heat-sensitive materials such as fruits and vegetables successfully can dry with this method due to the short drying time **[22]**. The IR methods are used to dry some food products such as mushroom **[23]**, carrot **[24]**, rainbow trout **[25]**, orange peel **[26]** and tomato slice **[27]**.

Other non-conventional drying methods are microwave drying (MVD) and radiofrequency drying (RFD) which both use electromagnetic radiation. As electromagnetic rays penetrate to the interior of food, it converts by a various mechanism to thermal energy which rises the food temperature volumetrically and causes an increase in the diffusion of moisture and water evaporation. The MVD and RFD were used for drying of different food materials, carrot powders **[28]**, onion **[29]**, garlic puree **[30]**, nectarine slices **[31]**, kiwifruit [32], carrot cubes **[33]** and potato flour **[34]**.

Electrohydrodynamic (EHD) drying is a non-conventional method that worked based on the generation of ion flow from a discharged electrode. Drying happens under the influence of generated airflow and change of ion direction inside the food. It is used for drying carrot, apple slices, tomato slice, mango, mushroom and quince slices **[35, 36, 37, 38, 39, 40]**. This study aims to present an overview of the application of some conventional and non-conventional drying methods in the food industry (e.g., hot-air drying, spray drying, microwave drying, infrared drying, radio frequency drying and electrohydrodynamic drying) and highlight their working mechanisms, critical factors which control the drying, their advantage and their application in the food industry.

The fundamental drying techniques applied in the food science and technology can be classified into conventional and non-conventional drying methods.

Conventional Drying Technology

Hot air drying

Hot air drying (HAD) is a traditional technology widely used to preserve agricultural products and foodstuff in the food industry. In this process, the food is exposed to a continuous hot air stream to separate moisture from products. HAD is a non-toxic, harmless, and cost-effective drying process which extends the shelf life, protects the products from microbial spoilage and undesired deterioration reactions, decreases the packaging, storage and transport costs **[41]**. However, the various transport phenomena such as heat, mass and momentum transfer simultaneously are occurred in the samples which creates complexity in the theory behind HAD unit operation. Different heat transfer phenomena such as convection and conduction along with various mass transfer mechanisms like as capillary and diffusion are participating in the HAD process **[1]**. Slow drying at a low temperature produces a dense food product while, fast-drying at high temperature creates less dense foodstuff but produces a crust on the surface of food **[42]**. Also, the long drying time of HAD process generally leads to produce a product with a higher amount of shrinkage and less amount of rehydration capacity **[43]**. The hot drying of many food products has been addressed in several studies such as Lentil seed **[9]**, tomato concentrate droplets **[44]**, pear slice **[45]**, corn **[46]**, Indian gooseberry shreds **[47]**, cocoa bean **[48]**, square, circle and triangle shape apple chips **[1]**, bamboo slice **[49]**, peppermint leaves **[50]**, pin nut seeds **[51]**, carrot slice **[24]**, persimmon **[10]**, shiitake mushroom **[52]**, mango cubes **[53]** and red pepper **[54]**.

Farias et. al. **[55]** studied the kinetic drying of longitudinally sliced banana at a HAD system and they used airflow with temperature ranges of 40 to 70°C with the relative humidity from 7.30 to 29.60%. The temperature, mass, and dimensions of samples were measured, and the thermal measurement of samples was done according to the geometrical parameters of the banana (longitudinal slices). It was stated that at the beginning of the drying process volume of samples suddenly decreased due to the high rate of water loss at this stage and the linear relation was found between shrinkage and amount of moisture removed. Also, they reported that shrinkage was affected by the geometric shape of the samples due to various shrinkage rates at the different directions (radial and axial). It was stated that drying occurred at a falling rate period and increases in air temperature and decreases in relative humidity lead to an increase in both drying and shrinkage rate.

Kian-Pour & Karatas **[1]** studied the effect of the different geometrical shapes of apple chips such as square, circle, and triangle on the drying kinetics of samples dried by hot air (temperatures of 110, 115, and 120°C; velocity: 1.75 m/s). It was revealed that triangle shape samples exhibited the higher Reynolds and Nusselt numbers, lower drag force, maximum diffusion coefficient, and minimum heat and mass transfer coefficients, highest fracturability and crispness, and the lowest drying time which were related to the characteristic length and sharp edge of samples and also due to development of amorphous structure at the temperature over 100°C. Onwude et. al. **[56]** dried pumpkin with different thicknesses (3, 5 and 7 mm) by hot air (from 50 to 80°C, and air velocity of 1.16m/s). The results revealed that an increase in the sample thickness caused an increase in drying time due to the long distance between the internal and external part of the sample which is the main reason for the increase in the travel time of moisture from inside to the outside of samples. It was stated that due to the same reasons, the heat and mass transfer were higher at the samples with 3 mm thickness and the activation energy was lower. Also, the authors reported that simultaneously increase in drying temperature and decrease in pumpkin thickness lead to a decrease in drying time more than 30%.

Senadeera et. al. **[10]** investigated the effect of air temperature (from 45 to 65°C) on the kinetics of drying, color, and shrinkage of persimmon. The results revealed that the L* value (lightness) of the dried sample was close to the brightness of fresh persimmon. The results of the Huge angle and total color difference demonstrated that drying at 65°C could protect the natural color of fresh samples and lead to decreases browning reaction during the HAD method due to lower drying time. Papoutsis et. al. **[57]** compare the effect of different drying methods (HAD, vacuum, and freeze-drying) (70, 90, and 110°C) on some bioactive compounds of lemon peel. It was stated that the maximum total phenolic content belonged to the samples dried with hot air drying at 110°C while, it was minimum at the products dried by freeze dryer. The phenolic materials are bound in the food structure and high temperature can change the cell structure and release this bioactive material from the food matrix. Also, it was reported that the antioxidant capacity of lemon peel dried with a hot air dryer or vacuum dryer was higher than samples dried with a freeze dryer.

Spray drying

Spray-drying is a unique one-step continuous drying operation that converts the fluid food to solid or semi-solid materials by atomization of liquid as individual droplets into the stream of hot drying air **[58, 59]**. The liquid (emulsion, dispersion, solution) is injected by a pump to the atomizer section which converted the feed solution into a spray of relatively small droplets. Generally, three type atomizer is commercially available such as 1) centrifugal disc atomizer which is suitable for high-capacity drying because of its flexibility and low maintenance, 2) pneumatic nozzles (two-fluid nozzles) which used compressed air to atomize the liquid food and are suitable for small size drying operation due to its less efficiency and the high cost of compressed air, and 3) pressure nozzles which the liquid food enter the nozzle core and left the nozzle with different angle under pressure (range of 5–7 MPa).

The droplets immediately contact with the hot gas flow (generally air) and due to the large surface area of small droplets, evaporation takes place rapidly therefore, the droplets' temperature remains low so the high drying temperatures can be used without negatively or significant effect on the product quality. The short drying time of the spray dryer makes it suitable for drying heat-sensitive materials. The dried products are collected at the bottom of the chamber and they are separated from the airflow via a cyclone by the centrifugal force, after that the air is expelled outside of the cyclone by passing among a filter. Convectional spray dryers provide powder of different sizes from **[6, 58, 59]**. However, the agglomeration can be used to modify some properties of food powder such as decreasing caking and lump formation, improve product porosity and solubility, modify fluidity, change product density and improve the homogeneity of products **[60]**. A schematic of the spray dryer is shown in Figure 2. The factors which affected the spray drying process and physicochemical properties of the product mainly are inlet and outlet air temperatures, feed and air rates, initial solid content of the feed, and residence time during the drying chamber **[58]**.

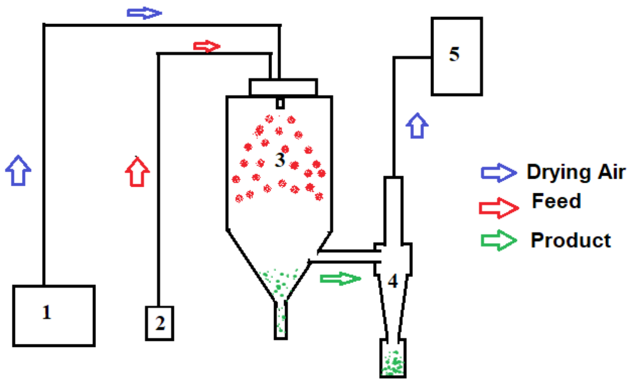

Figure 2. A schematic of spray dryer for drying of foodstuff. 1) Air compressor, 2) Feed, 3) Drying Chamber, 4) Cyclone, 5) Filter

Spray dryer can be used for encapsulation of active compounds in food such as essential oils, vitamins, probiotics, antioxidants, enzymes, color materials, and additives. The encapsulations are used for 1) protect sensitive food compounds against pH, temperature, oxidation, hydrolysis, etc., 2) maintain the nutrition, 3) permit adding nutrient, flavor, color pigment, taste-enhancer materials after processing, 4) prolonged-release of bioactive ingredients into the formulation, 5) preserving volatile materials, 6) masking unwanted flavors and aromas, 7) improve the antibacterial efficiency of compounds **[61]**. The encapsulation is used to entrap the target material (core) into a thin film (wall or carrier). The encapsulating agents (wall material) have an important effect on the storage stability, encapsulation efficiency, protection of core materials, controlled release, etc. Different type of wall materials such as carbohydrates (cellulose, carrageenan, maltodextrin, dextran, sodium alginate, starch, gum Arabic, alginate, guar gum, pectin), proteins (zeini gluten, whey protein, albumin, etc.), and lipids/waxes (phospholipids, beeswax, etc.) are used in encapsulation of bioactive compounds **[62]**. However, to obtain an encapsulated product with desired properties, both process conditions and the encapsulating materials (such as surface tension, viscosity, air, and feed temperature, atomizer conditions) need to be optimized **[61]**.

The encapsulation of different carotenoids compounds using carbohydrates as wall materials was reported such as encapsulation of total carotenoids by 15% -30% w/v maltodextrin **[14]**, lycopene by (10% and 20% w/v)) maltodextrin **[15]**, β-carotene by starch **[16]**. Also, various protein compounds used for encapsulation of carotenoids such as gelatin **[11]**, soy protein isolate **[12]**, whey protein **[13]**. Álvarez-Henao et. al. **[63]** used spray drying process to improve the stability of lutein and protect its functionality as an antioxidant. Maltodextrin, gum arabic, and modified starch were used at the different concentration as the core materials and mixture of core and wall materials was spray-dried (air: 50m^3/h, inlet temperature 185°C; feed:4 mL/min). The results of the study of Maroof et al. **[61]** shown that the yield of encapsulation ranged from 9.90 to 32.7%, the encapsulation efficiency was varied between 2.38% and 91.94%, the particle-sized changed from 1.64 to 14.20 μm. They reported that the mixture of Arabic gum: maltodextrin: modified starch with a ratio of 33.3:33.3:33.3%, exhibit the formulation to protect the lutein and increased its stability during the 2-day storage.

Osorio et. al. **[17]** used spray dryer for encapsulation of the guava extract and used maltodextrin and Arabic gum as the wall materials. The retention of volatile compounds due to encapsulation was reported. It was stated that Arabic gum modified fluidity during dehydration, but it caused a decrease in the thermal stability of the dried powder. Liu et. al. **[18]** used spray dryer to improve the solubility and bioavailability of curcumin. The inlet temperature of the drying medium was adjusted at 110 and 150°C and the whey protein isolate solution (5wt %) was used as a wall material for encapsulation of curcumin (59.5 mg/mL). The results revealed that encapsulation increased both the solubility and antioxidant properties of curcumin. Jansen-Alves et. al. **[64]** investigated the encapsulation of propolis extract with a spray dryer by using rice, pea, soybean, and ovalbumin proteins as the encapsulation agents. Encapsulation efficiency was between 70.2 and 90.20 % and the highest antioxidant activity belonged to the rice protein. Also, dried powder exhibited various shapes and sizes and they showed different physical attributes such as enthalpy, the glass transition temperatures, solubility %, water absorption %, and hygroscopicity %. Aquilani et. al. **[19]** used spray dryer for encapsulation of fish oil and added it to the Cinta Senese pork burgers. The comparison between burgers with added encapsulated fish oil (M) and burgers with add normal fish oil (N) demonstrated that after storage and cooking of burgers, the fatty acids of EPA and DHA were better protected in M burgers than in N burgers. It was stated that microencapsulation of fish oil was an efficient way to protect EPA and DHA from oxidation. Furthermore, sensory evaluation of products indicated that the chilled storage can be used for M products while frozen storage needs to use for N products. Pino et al**. [65]** used maltodextrin (5- 15% w/w) mixed with gum Arabic (10% w/w) to the encapsulation of cold-pressed winter squash seed oil by spray dryer (140-180°C). It was stated that encapsulated seed oil had higher antioxidant activity than raw oil due to the barrier properties of wall material against oxidation of the oil.

Also, the spray dryer has a vast application in the production of dried bacteria, as it can produce a huge amount of product with a lower energy cost compared with the freeze dryer. Bustamante et al. **[20]** used spray dryer for encapsulation of two probiotic bacteria: *Bifidobacterium infantis* and *Lactobacillus plantarum*.

The mucilage (M) and soluble protein (SP) extracted from chia seed and flaxseed were used as wall materials. It was stated that the use of ternary blends consists of maltodextrin, M, and SP as the wall material produced encapsulated *B. infantis* and *L. plantarum* with a high level of probiotics survival (more than 98%) during spray drying and viability during storage at 4°C. Also, encapsulation improved the resistance of *B. infantis* and *L. plantarum* to simulated gastric juice and bile solution. Furthermore, when the encapsulated probiotic powder was combined with the instant juice powder, after the long-term storage (45 days) at 4°C the high amount of probiotic viability (>9Log_{10}CFU/g) was observed. The different percent of survival (%) for various probiotics was reported by many authors. For instant 50% for *L. rhamnosus* GG encapsulated in micellar casein and whey protein solutions **[21]**, 69% for *L. plantarum* A17 encapsulated in whey protein isolate pH:7 and 39.3% at pH:4 **[66]**, 60% for *Lactobacillus casei* BL23 encapsulated in sweet whey fermented growth medium with inlet drying temperature of 140°C. Also, the survival (%) increased to 100% when the *L. casei* BL23 dried at 127°C however, *Propionibacterium freudenreichii* ITG P20 showed 100% survival at both 140 and 127°C **[67]**.

The major problems with conventional drying technology are long drying times and nutrition loss along with poor sensorial attributes of dried food (for hot air drying and sun drying), high energy consumption and operating cost (for vacuum and freeze-drying), unique demands for the form of dried food (for heat pump assisted drying methods and spray dryer), unsufficient reduction in the water content of food (for osmotic drying) **[68]**. To overcome these problems, non-conventional drying technologies can be used.

Non-Conventional Drying Technology

Infrared drying

In infrared (IR) dehydration the IR rays generated from the heating power can penetrate to a depth of a wet foodstuff and increase its temperature. Therefore, the increases in the diffusion rate of moisture in the sample lead to the evaporation of water. The advantages of IR drying compared to conventional drying includes superior energy efficiency, high heat transfer rate, and uniform heating of product **[2, 69].** The short drying time in this method makes it suitable for heat-sensitive materials such as fruits and vegetables **[2, 22, 69, 70].**

Infrared radiation (IR) is an electromagnetic wavelength in the range of 0.78 µm (visible light) and 1000 µm (microwave). IR radiation can be classified into three sub-groups. Near-infrared (NIR) with the wavelength between to , mid-infrared (MID) which appear in the wavelength of 1.40 µm to 3 µm and far-infrared (FIR) radiation in the wavelength of *3* µm to 1000 µm. The penetration depth (PD) demonstrates the length at which the intensity of IR inside the food is nearly 37% of IR value at the food surface **[69]**. The penetration depth of IR radiation is dependent on the composition and properties of food such as density, moisture content, and porosity, as well as properties of irradiated medium **[22]**. The NIR (short wavelength) seems to be better in the drying of food with higher thickness, in contrast, FIR (longer wavelength) showed better results in drying of foodstuff with a lower thickness **[69]**. Generally, the collision of electromagnetic radiation with food causes alters in the electronic, rotational and vibrational situation of atoms and molecules **[71]**. As the food molecules expose to the IR radiation they start to vibrate with the frequency of 60,000–150,000MHz. Therefore, the creation of intermolecular friction due to this vibration leads to the rapid increase of internal temperature and heats the food which increases the water vapor pressure inside the food **[72]**.

When a food product is exposed to IR radiation, three situations may happen such as the reflected, absorbed, and transmitted radiation. Absorption wavelength (µm) of chemical groups such as Hydroxyl group (OH) in water and sugars, carbonyl group in lipids and proteins are different from each other **[69]**. The absorption spectrum of IR wavelength for different compositions in food is 3, 4.7, 6, and 15.3 µm, for water, 3–4 µm and 6–9 µm for proteins **[73]**, and 3 µm and 7–10 µm for sugar, 3–4 µm, 6 µm, and 9–10 µm for lipids **[22]**. Pawar & Pratape **[74]** reported the usage of different infrared wavelength in the drying of various food product such as NIR drying for apple, tomato, parboiled rice, pomegranate arils, hazelnut, and carrot; MIR drying for meat, vegetables, seedless grapes, shredded squid; FIR drying for Barley, citrus press cake, tiger prawns, onion, potato, barely, cashew, brown rice. The main parameters which need to consider during IR drying are IR intensity and IR time, the distance among food surface with IR producing element, and finally the thickness of foodstuff. Therefore, with the correct selection of these variables, it is possible to control the drying time, energy consumption, and quality attributes of dried food. It was stated that an increase in drying rate and moisture diffusion and decrease in drying time can achieve by an increase in IR temperature and IR intensity. In contrast, an increase in the distance between the IR radiation source and the surface of the foodstuff causes an increase in drying time. Furthermore, food materials with higher thickness exhibit higher drying time compare with thin material **[23, 26, 27, 75]**. Doymaz **[24]** studied on the drying of carrots at different IR power (62, 74, 88, 104, 125W) and they observed that at all IR intensity, increase the temperature from 20 to 50°C, improved the rehydration ability of dried carrot due to change in the cell wall. Also, an increase of IR decreased the *L**value of products and produced carrots with a darker color. Ismail & Kocabay **[25]** compared the infrared drying (at power levels of 83, 104, and 125 W) and microwave drying (at power levels of 90, 180, 270 and 360 W) of Rainbow trout (*Oncorhynchus mykiss*) fillets. They demonstrated that drying caused an increase in the "*L*" and "*b*" values and at the same time it decreased the "*a*" value of sample. Furthermore, increased in the IR power, decreased the "*L*" value and changed in the color parameters in IR drying was more than microwave drying. Also, microwave drying exhibited higher activation energy compare with IR drying.

Bejar et al. **[26]** studied the impact of IR drying at different temperatures (40, 50, 60 and 70 °C) on the total phenols, water (WHC), and oil holding capacity (OHC) of orange peel. They reported that infrared drying significantly increased the WHC while decreased OHC. IR drying at higher temperatures reduced the WHC, but it has not influenced the OHC of samples. Besides, total phenolic compounds were found to be higher in the samples dried at higher IR temperatures (60 and 70 °C). Wang et al. **[23]** compared IR drying and hot air drying of mushroom chewing tablets. Both experiments were conducted at 60, 70 and 80 °C. They reported that IR dying improved the drying rate and decreased the drying time of samples compare with hot air drying. Also, the texture properties of samples showed that samples dried with IR had lower hardness and chewiness values which may be related to the faster evaporation of water compare with hot air dryers. As IR can easily penetrate the inside parts of the materials, make the facility in the transfer of heat, therefore, IR drying is much more rapid than hot air drying and the rapid evaporation of moisture from interior tissue of mushroom chewing tablets has a puffing effect and produce softer structure compare with hot air drying. Also, sensory evaluation demonstrated that the overall acceptance of samples dried with the IR method was higher than those dried by hot air techniques and the highest acceptance score belonged to the samples dried with IR at 70°C.

Abano et al. **[27]** used three different levels of distance between IR source and tomato slices (38 to 50 cm), and various thicknesses of the sample (7 to 11 mm) in catalytic infrared drying of fresh tomato slices. The results revealed that when the distance decreased, drying time and ascorbic acid content of tomato slice were significantly decreased, while lycopene content of dried tomato slice and the color parameters such as the ratio of redness to yellowness increased. Furthermore, samples with higher levels of thickness had a longer drying time and a higher amount of lycopene but a lower amount of ascorbic acid. Also, the non-enzymatic browning index, a^*, b^* *and* L^* values of dried tomato decreased with increasing the thickness of samples. Li et al. **[75]** reported that moisture diffusivity of mid-infrared dried beef jerky was 158.1% higher than that of hot air-dried samples. Also, the time and energy consumption of IR drying was lower than hot air drying. The authors demonstrated that mid-infrared drying can boost protein denaturation in myofibril structures of beef jerky, lead to more immobile water inside the myofibrillar matrix migrated to the outside of it which increased the levels of free water inside the samples and subsequently accelerating the diffusion of free water to the surface.

Microwave drying

Microwave is electromagnetic radiation that can spread through space by both electric and magnetic fields **[76]**. Microwave drying is another drying method that has many advantages compared to hot air drying such as:1) decrease hardening of the food product by volumetric heating from the center to the surface of the sample, 2) significantly decrease drying time via increase heat and mass transfer, 3) increasing drying rate and moisture diffusion 4) make a facility to separate bound water molecule which removing of them are difficult in the hot air drying **[76]**. Microwave heating is done by change of energy from electromagnetic radiation type to thermal type. It penetrates the food and increases the temperature of the material volumetrically which leads to an increasing in the rate of diffusion and pressure gradients inside the food materials. Heating at microwave methods takes place by two methods: dipolar reorientation and ionic conduction.

Dipolar reorientation

In the dipolar reorientation mechanism, the water molecule of foods due to their dipolar nature, try to align themselves with the electric fields, therefore, rotated in direction of electric fields **[77]**. But as the number of change in direction of electric fields is very huge (2.45 billion times a second), the rapid rotation of water molecules creates friction and generate heat in the food samples which exposed to this electric field and produce volumetric heating. The efficiency of microwave heating on food with high water content (such as fruit and vegetables with near 80% of dipolar water molecules) is higher compare with foods contain a high amount of fats and sugar (with lower molecular dipole rotation) **[76]**.

Ionic conduction

Ionic conduction which in this mechanism electric fields produced inside of foods by microwave rays cause migration in the ions presented in food (for example ions in salty foods) and the movement of these ions generate heat in food products **[76]**.

The effect of microwave drying on the different properties of various food products has been investigated such as drying kinetics, color and structure of Trabzon persimmon **[78]**, aroma and phenolic compound of carrot powders **[28]**, bioactive compound and antioxidant activity of green peas **[79]**, kinetic drying of onion **[29]**, water activity, color, optic index and volatile oil of garlic puree **[30]**, drying kinetics and texture of nectarine slices **[31]**. However, to increase the performance of drying, microwave drying uses simultaneously with other drying methods mainly hot-air dryers for fast drying of foodstuff **[43]**.

The effect of microwave vacuum drying (MVD), pulse-spouted vacuum microwave drying (PSMVD), pulse-spouted microwave drying (PSMD), and microwave freeze-drying (MFD) on the drying kinetics, color, apparent density, texture, and microstructure of green soybean have been investigated **[80]**. According to the results, green soybean dried with MFD methods showed good bright color and preserved the original shape of samples. However, in terms of the quality of dried soybean, PSMVD/PSMD exhibited a better effect than MVD. Çelen **[78]** studied the effect of microwave drying (120, 350, 460, and 600 W and 2450 MHz) on the drying kinetics, color, and microstructure of Trabzon persimmon (5, 7, and 9 mm). The results reveal that as the microwave power increased, drying time and energy consumption decreased, while the diffusion coefficient and drying rate increased. However, drying at higher microwave power, create higher temperature with non-uniform distribution of microwave energy inside the sample which leads to burns in some regions. Furthermore, long drying duration also can create burned region at the lower microwave power. The authors recommended that supported microwave drying with conventional drying can produce a dried sample with better color. In terms of microstructure, it was stated that increasing in microwave power level leads to an increase in the pores number and pore growths **[78].** Keser et al. **[28]** investigated the effect of different microwave power levels of 150 W to 450 Won the aroma and phenolic compound of powdered carrot. It was stated that an increase in the level of furan, alcohol, aldehyde, acids, and pyrazine in dried carrot powders were related to the microwave power. Also, the amount of some terpenes such as elemicin and myristicin were higher at the samples dried at lower microwave power (150W). Furthermore, the phenolic and antioxidant capacity of samples dried at microwave with lower power (150 W) were preserved better in comparison with other samples. Besides, their results revealed that dried powdered carrots with higher *L** values had lighter color than fresh carrots and as microwave powered increased, products became darker which may be related to the generation of higher temperature at a higher level of microwave power. The similar results relation between microwave power levels with the color of products were reported by different authors **[81, 82]**. Therefore, the authors recommended using low microwave power in the drying of carrots.

Radio frequency drying

The principle of drying by radio frequency (RFD) wave is the same as microwave drying (MVD). Both of them are known as dielectric heating due to their electromagnetic energy which can penetrate to food interior, convert to thermal energy, and rise the center temperature of food **[3]**. However, the main parameter which separates RFD from MVD is the frequency range. The electromagnetic waves in the range of 10 to 300 MHz are used for drying food products. When a food material with dielectric property (involves polarized molecules, positive and negative charged ions) is exposed to an electrical field, each positive and negative ion inside food moves toward oppositely charged regions known as "ionic migration." Besides, the movement of dipolar molecules is named "dipole rotation." Therefore, both ionic migration and dipole rotation mechanisms create friction between molecules, which generate heat inside the sample. The main factor that has an impact in the RFD of foodstuff are dielectric and thermal attributes of food and also distributions of electromagnetic field **[68]**. However, non-uniform heating of the material in RFD leads to overheating in corners, and edges of food **[83]**.

Wang et al. **[84]** used radio frequency drying (electrode gap:14, 15 and 16 cm) combined with hot air drying (temperatures 30, 40, and 50°C) to drying in-shell hazelnuts. They demonstrated that at the electrode gap of 14 cm and temperature of 40°C hot-air assisted radiofrequency (HARF) decreased drying time to 22 minutes compared with hot air drying (420 min). Also, the drying rate and mass transfer coefficient were higher compare with hot air drying, while energy consumption was lower. Furthermore, the total phenolic content of in-shell hazelnuts dried with HARF was higher than hot air dries samples while their peroxide value and polyphenol oxidase activity were lower than hot air-dried products. RFD is used by different authors for various foodstuff such as carrot cubes **[33]**, chicken powder **[85]**, kiwifruit **[32]**, potato flour **[34]**, apple slices **[86]**.

Electrohydrodynamic (EHD) drying

In the EHD drying, a discharge electrode (such as a sharp needle or thin wire) is exposed to high voltage, therefore an ion flow generates and collisions between charged ions with non-charged molecules produced an ionic or corona wind. The movement of corona wind to the collecting electrode speeds up under the influence of electric fields and the speed of wind can be reached to 200 m/s. Also, the collision of ionic wind with air molecules creates an airflow from 0.1 to 10 m/s. The contact of ionic wind with the material disturbs the saturated layer of air on the food surface and enhance the evaporation phenomena. Besides, water molecule inside the food change their direction according to the electric field and cause a reduction in the entropy which leads to decreasing the temperature of the food being dried. Therefore, heat-sensitive foods can be successfully dry by this method **[87, 88]**. A schematic of EHD drying was shown in Figure 3.

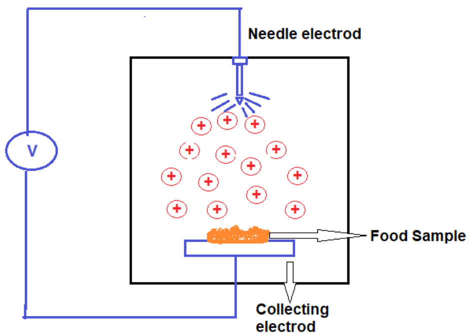

Figure 3. A schematic of electrohydrodynamic drying of food **[36, 87]**.

Martynenko & Zheng **[36]** studied the electrohydrodynamic drying of apple slices. Voltage adjusted between 0 and 15 kV and distance between needle and plate electrode fixed at 22 mm. It is stated that EHD drying had not a significant effect on apple browning at 5 and 10 kV and they showed that as air velocity increased, quality degradation decreased. Ding et al. **[35]** exposed carrot slice with 5 mm thickness on EDH drying with the voltage of 10 -30 kV and electrode gap of 100 mm. The results revealed that carrots dried by EHD had higher carotene content than sample dried with oven dryer and the EDH drying cause improvement in rehydration ratio. Different authors used EHD for drying of food products such as tomato slice **[37]**, mango **[38]**, mushroom slices **[39]** and quince slices **[40]**.

Multi-stage combined drying

Nowadays, many combinations of drying techniques are used to overcome the deficiency of a single drying process which involved parallel and tandem drying. In parallel drying methods products are dried simultaneously by two or more drying techniques while, tandem drying refers to the use of one drying technique followed by one or more other dehydration processes **[3]**. Some combined parallel drying systems were shown in Table 1.

Table 1. Multi-stage combined drying system in the food industry

Technique	Results	References
RFD + HAD	This method produced uniform dehydration and products with higher quality compare with HAD	**[89]**
RFD + HP	It reduced the color loss of dried food samples. The produced cracking (due to shrinkage) can be eliminated	**[89]**
MVD + SBD	More uniform drying compares with MVD due to the fluidization of particles which make the facility in the heat and mass transfer	**[90]**

MVD + PSBD	The main disadvantage of MVD is non-uniform drying, however, combined a pulse spouted bed drying to MVD can produce more uniform and faster drying compare with MVD	**[91]**
MVD + PSBFD	The combination of MVD with pulsed-fluidized bed freeze dryer enhanced the uniformity of drying by pulse agitation. This method can protect stem lettuce slices from colour loss, it can increase rehydration capacity and produce a higher level of hardness after rehydration	**[92]**
HP + FIR	A combination of heat pump drying with far-infrared drying can decrease the drying time and can improve some quality parameter such as nutritional level, sensorial properties, and functional attributes of food products	**[93]**
FIR + LPSSD	According to the use of low drying temperature at low pressure, the combination of far infrared drying with low-pressure superheated steam drying can be suitable for heat-sensitive foodstuff	**[94]**
IR + FD	Decrease drying time and it can produce crispy texture in food	**[95]**
EHD + VFD	By a combination of EHD drying and vacuum freeze-drying, the advantage of low energy consumption of EHD dryer and production a high-quality dried food by vacuum freeze dryer can merges	**[96]**
EHD +SD	In this method, a low-voltage nozzle is used which give a moderate charge to droplets and the charged particles are collected by an EHD field	**[97]**

CONCLUSION

This review investigated various conventional and non-conventional drying methods for drying of food materials. These technologies could be used to decrease moisture content and water activity of food products to protect them from chemical, and microbiological deterioration. Among the conventional drying technology, hot air drying, and spray drying were reviewed according to their vast application in the food industry. However, the main concern about conventional drying is low energy efficiency and the emission of hot exhaust gases to the environment. Therefore, non-conventional drying methods were reviewed, and their mechanisms, advantage, and applications were studied. Among the non-conventional drying techniques microwave drying, infrared drying, radio frequency drying, and electro hydrodynamic drying were investigated. These data could be useful for food industries to make enlightened decisions on the selection of proper drying methods for food products.

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