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Vacuum processing of food–a Mini Review

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Abstract

Conventional food processing operations such as frying, drying, and blanching which are performed under atmospheric condition sexposures product to high processing temperature. In addition to the potential product contamination from exposure to atmospheric conditions, other challenges/issues include nutrient losses, changes in the product sensory attributes and lengthy processing time. In order to minimize the aforementioned disadvantages, the food industry has adopted novel techniques like vacuum processing for operations such as frying, cooling, drying, packaging etc.

Keywords: food processing, vacuum pressure, standard atmosphere, lacking, food products, vegetables, kiwifruits

Introduction

The term *vacuum* is generally used to represent a volume or state of space in which the pressure is considerably less than atmospheric pressure. In the pressure measurement system, normal vacuum pressure is expressed in millimeters of a column of mercury, and 760millimeters of mercury is designated as 1 standard atmosphere. Another conventional unit of pressure, especially at lower pressure is the Torr, which approximately equals 1 millimetre of mercury. The SI unit for vacuum pressure is Pascal's and standard atmospheric pressure is 101.325kPa. A perfect or absolute vacuum, which denotes a space that is entirely lacking of matter, is basically unrealizable.

Vacuum frying

Vacuum frying operation is carried out at pressures below atmospheric pressure. Frying changes the color, appearance, texture and product composition; rendering the fried product palatable to the consumer. Vacuum frying has been applied to a wide variety of food products including snacks and treats. A large application of this technology is reported for fruits and vegetables. The latest reports comprise of vacuum frying of apple, apricot, banana, jackfruit, green and gold kiwifruits, carrot, mushroom, potato, shallot, sweet potato and purple yam.

Vacuum frying systems

A vacuum frying system essentially includes three components, namely a vacuum frying chamber, a refrigerated condenser and a vacuum pump. The vacuum frying chamber is a hermetic vessel facilitated with an oil heater and a frying basket. The frying basket is raised and lowered into the heating medium with a lift rod. The lift rod is connected to a spinner motor that centrifuges the product to eliminate surface oil. The refrigerated condenser traps the steam released during frying and condenses on a cold surface. The vacuum pump provides the required reduced pressures for the process.

Andres–Bello et al.[1] identified three vacuum frying equipment based on size: laboratory, pilot and industrial scale system and in terms of processing requirements: for batch or continuous processes. The authors have accordingly elaborated on three examples of vacuum frying systems.

Yamsaengsung et al.[2] used a gas–heated vacuum frying chamber, a water–cooled condenser and a liquid ring vacuum pump to develop a vacuum frying system. The fried product was centrifuged at 450 rpm within the frying chamber. Sothornvit[3] studied different patterns of vacuum frying system used in processing. He developed a vacuum frying chamber equipped with heated oil from another chamber, a cooling tower type condenser and an oil–sealed vacuum pump. Diamante et al.[4] used a vacuum frying chamber with a water–cooled condenser cooling tower and liquid ring vacuum pump to vacuum fry jackfruit chips. After frying, the jackfruit chips were centrifuged at atmospheric pressure in a separate machine. Diamante et al.[4] also reported on vacuum frying of gold kiwifruit slices. The system used consisted of a steam–heated vacuum frying chamber, a water–cooler condenser and an oil–sealed vacuum pump. The fried products were then centrifuged at atmospheric pressure using another unit. Pandey & Moreira[5] used a vacuum fried potato chips in a system consisting of an electric–heated vacuum frying chamber, a refrigerated condenser and an oil–sealed vacuum pump. The vacuum fried chips were centrifuged within the chamber at speeds of up to 750 rpm.

Advantages of vacuum frying

Vacuum frying is an alternative way to enhance the quality of fried food products compared to atmospheric frying.[6] The foremost factors that impact fried products are the frying time–temperature combination of the process; the correct combination is necessary to produce a food product with acceptable physical attributes.[1] Dueik & Bouchon[6] reported that vacuum frying pointedly lowered the final oil content in comparison to atmospheric fried food products and it also significantly reduced the rancidity of the oil used for frying. Most of the benefits from vacuum frying could be attributed to usage of low temperatures (105°C), the minimal exposure to oxygen, which diminishes the adverse effects on the oil quality.[7] The process is reported to preserve the natural colour and flavour,[8] reduce the acrylamide content[9] and preserve nutritional compounds, such as vitamins and minerals in the fried product.[10] Vacuum frying has been presented as a good option to achieve high quality food products with better sensory attributes due to the reduced oxidation, reduced frying temperatures and much shorter processing times compared with other techniques.[10]

Disadvantages

In economic terms, investment cost of vacuum fryers is much higher than conventional fryers, because vacuum frying technique is basically designed for large scale industry. There is a lack of an economical vacuum fryer that small scale manufacturers can afford without financial support from external agencies.[11]

Significance of vacuum frying and its benefits in processing of food products

Oil uptake is one of the vital quality parameters of fried food products, which renders it unsuitable as a healthy food.[12] The intake of oil and saturated fat has been associated with significant health concerns, including coronary heart disease, cancer, diabetes, and hypertension.[13] Other unacceptable effects resulting from high temperature frying involved exposure to oxygen are the decrease in nutritive compounds, and the production of toxic molecules in the food or the frying oil.[14] The low pressure during frying results in fast air diffusion into the porous structure developed during frying. The blocking of oil into the product leads to lower absorption of oil than during atmospheric frying. Vacuum fried carrot slices were found to have approximately 50%(d.b.) decrease in oil absorption compared to atmospheric fried slices under thermal driving forces of 60°C–80°C.[15]

Due to the typical mass transfer phenomenon during vacuum frying, the oil adsorbed to the surface of the fried product (and not in the inner pores of the product as observed in regular atmospheric frying). This necessitates the downstream operation of deoiling which could be achieved by centrifugation or by pressurisation post frying. Moreira et al.[16] reported a centrifuging system (750rpm for 40s) for deoiling of potato slices fried for 360s interval in a lab–scale vacuum fryer system ($P<1.33$kPa) at 120, 130, and 140°C. Non centrifuged samples fried at 120°C for the same time had a final oil content of 0.43g/g product compared to 0.097g/g product for the centrifuged samples.

During frying, the oil is exposed to air, water, and heat resulting in thermal, oxidative, and hydrolytic decomposition of the oil. Initially, fats and oils are oxidized to form the primary oxidation products, namely, hydroperoxides. These peroxides are enormously unstable and decompose via fission, leading to the formation of free radicals leads to a variety of chemical products, such as alcohols, aldehydes, ketones, acids, dimers, trimers, polymers, and cyclic compounds. Palm oil, lard, and soybean oil were heated under vacuum at 105°C for 20min each hour in an 8–h shift. Results showed that palm oil and lard have greater thermal stability than soybean oil.[7]

Tareke et al.[17] stated that acrylamide, a genotoxic carcinogen, is generated predominantly in carbohydrate rich food products during high–temperature processes, including frying. Foodstuffs such as French fries, potato chips, and other deep–fat fried, or oven–cooked potato products, including crisp bread, biscuits, crackers, and breakfast cereals analysed for the compound showed high levels of acrylamide.[17] Mottram et al.[18] identified asparagine, a major amino acid found in potatoes and cereals, as the key component in the formation of acrylamide which was formed by the Maillard reaction pathway. Vacuum fried potato slices at 118 °C produced low acrylamide content (6%) and desirable yellow golden color and texture attributes compared with those fried in the conventional fryer.[9]

Troncoso et al.[19] fried pre–treated potato slices at temperatures 120 and 140°C under both vacuum (5.37kPa, absolute pressure) and atmospheric pressure conditions until they reached a final moisture content of 1.8kg water/100kg (wet basis). The colour of the potato slices fried at atmospheric conditions were described as ''darker'' and ''worst'' than the potato slices fried under vacuum. Texture quality was considered ''better'' for vacuum fried chips and overall quality improved with vacuum frying compared to atmospheric frying.

Heat and mass transfer during vacuum frying

Yamsaengsung et al.[20] developed a two–dimensional model to predict the heat and mass transfer phenomena during the vacuum frying of potato chips using the Finite Element toolbox in MATLAB 6.1. They simulated the heat transfer process by integrating convection of heat from the surface to the product, the conduction of heat into the product, and a loss of heat due to evaporation. The mass transfer process was divided into two periods: (1) water loss and (2) oil absorption.

It postulated that during frying operation, the heat from the oil is transmitted to the product surface and is then conducted to the product's centre, resulting in an increased temperature.[21] Water evaporates as the product temperature reaches the boiling–point temperature. This process is described as a Stephan type heat transfer problem, and attributed to the presence of a moving interface that divides two regions of physical and thermal properties.[21]

Ni & Datta[22] developed a multiphase porous media model suitable for studying deep fat frying process since the model encompasses all transport mechanisms such as molecular diffusion, capillary, and pressure driven flow and the properties of the phases (oil, water, vapour, and air) are retained in the model.

Mir–Bel et al.[23] analysed the effect of temperature and reduced pressure on the convective heat transfer coefficient, h. During frying, h changes considerably, reaching a maximum between 700–1600$\mathrm{Wm^{-2}K^{-1}}$ in vacuum frying and 800–2000 $\mathrm{Wm^{-2}K^{-1}}$ in atmospheric frying of food products with different area/volume ratio. The value of h was computed from surface temperature and the results obtained during vacuum frying were compared with those obtained from conventional frying.

Tang Duangdee et al.[24] stated that the heat transfer coefficient was an important parameter in the modelling and calculating of fryer systems. The significant role of heat flux in the formation and quality of the crunch layer and the development of characteristic properties of the final product such as the colour, texture or flavour has been discussed by Sosa–Morales et al.[25]

Since heat transfer coefficient is dependent on the specific set–up of the system, no one standard method is reported for its determination. Commonly applied methods include measuring the surface temperature of the food product over time and the corresponding water loss.[26] Alvis et al.[27] discussed the three methods to compute the convective heat transfer coefficient, namely by steady–state measurement of surface temperature, transient measurement of temperature, and heat flux measurement at the surface.

Pandey & Moreira,[5] and Yagua & Moreira[28] determined the convective heat coefficient during vacuum frying of potato chips. They found that h changed noticeably as frying proceeded, attaining a maximum between 2200 and 2650$\mathrm{W/m^2K}$. Moreover, it increased with temperature during the initial stages of the frying process and reduced over time. However, the h values obtained were not compared with products fried under atmospheric condition and the effect of vacuum on convective heat transfer during frying was not elucidated in this study.

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Troncoso et al.[19] determined the kinetics of water loss and oil uptake during frying of pre–treated potato slices under vacuum and atmospheric pressure. The potato slices were fried under vacuum (5.37kPa, absolute pressure, at 120, 130 and 140°C) and atmospheric conditions (at 180°C). The developed two models based on the Fick's law described water loss: (i) with a constant effective diffusive coefficient; and (ii) with a variable effective diffusive coefficient. Moyano & Berna,[29] applied Fick's law of diffusion to model the water loss in fried food products with successful settlement between experimental data and calculated values. This model was applied to describe water diffusion in solid foods considering an effective coefficient assumed to include all water transport mechanisms. However, in addition to diffusion, it is expected that water might also be transported through other mechanism like hydrodynamic gradients and capillary flow based on the material structure.[30] It may be difficult to completely characterise these entire factor using a single effective coefficient of diffusion. Garayo & Moreira[31] determined the kinetics of oil absorption in vacuum fried potato slices under different vacuum conditions at different pressures and temperatures, and concluded that oil uptake in final potato chips was affected considerably by the frying temperature and level of vacuum. Tan & Mittal[32] stated that donuts fried under vacuum absorbed significantly more oil (14.5–35.8g oil/100g dry basis; vacuum levels of 3, 6 and 9kPa) compared to the donuts fried at atmospheric conditions (13.1g oil/100g dry basis). This is in contrast to the results reported by other workers crediting vacuum frying with significantly lower oil absorption.[15]

Vacuum cooling

Vacuum cooling is an advanced cooling technology based on rapid evaporative cooling method for porous and moisture foods. Vacuum cooling has been applied for pre–cooling of horticultural products such as fruits and vegetables to extend their storage life by decreasing post–harvest thermal deterioration. Recent research has been concentrated on the application of vacuum cooling for cooked meats, fishery products and ready to eat meals, for which rapid cooling is beneficial in controlling growth of micro–organisms and preserving quality of the products. Unlike vapour–compression refrigeration, vacuum cooling is based on liquid evaporation to produce a cooling effect, rather than by blowing cold medium over the food product.[33] Speed and efficiency of vacuum cooling are unsurpassed by any conventional cooling method, especially for boxed or palletised products.

Sun & Zheng[34] stated that vacuum cooling is achieved by the rapid evaporation of moisture from the surface as well as within the products. During water evaporation, heat is absorbed into maintain higher energy level to facilitate the molecular movement in gaseous state. The amount of latent eat required is supplied from the product or from the surroundings. The amount of water evaporated is dependent on the surrounding vapour pressure. At a pressure of 1 atm, water evaporates at 100°C; however, water will boil at lower temperature when the pressure is reduced to below 1atm.

Vacuum cooling system

Depending on the application, vacuum cooling system installations vary in size and shape.[35] The basic components consist of a vacuum chamber, vacuum pump, vapour condenser and allied components. In the vacuum chamber, the vacuum pump is used to create vacuum and the food product is sealed airtight and cooled. Various vacuum pumps can be used, but the most commonly used design is the oil–sealed rotary pump.[36] During vacuum cooling, there will be generation of vapours. For example, a reduction from 72°C to 4°C is typically associated with a loss of 400–500g of moisture, requiring the vacuum pump to handle over 25m^3 of vapour at 22 mbar.[37] A vapour condenser is usually installed in the system to condense the vapour to water and discharged through the drain.

Applications of vacuum cooling

Fruit and vegetables

Leafy vegetables like spinach and lettuce are ideal candidates for vacuum cooling due to their large surface area to volume ratio being suited for faster evaporation.[38,39]. Lettuce was vacuum cooled prior to PVC film wrapping or post packaging in perforated polypropylene bags.[40,41] Vacuum cooling successfully reduced lettuce temperature from 25°C to 1°C within 30min.[42] Lettuce stored at ambient temperature had 3–5 days shelf life, while vacuum cooling in combination with cold storage at 1°C was found to prolong shelf life to 14 days.[40,41]

Vacuum cooling for mushroom was found to result in approximately 3.6% of weight loss, which was greater than 2% in air blast chilling.[43] During storage, the vacuum cooled mushroom had less weight loss compared to air blast cooled, compensating for the water loss during cooling. The mushrooms can absorb as much as 6% of their weight in water if they are wetted for 5min. therefore; wetting mushrooms before cooling is an effective method to reduce the weight loss during vacuum cooling. Pre–wetting of mushroom before vacuum cooling was reported as an effective method to increase product yield. Vacuum cooling has been accepted commercially in the countries like United States, the United Kingdom, Ireland and other parts of Europe, and has been found to cool mushrooms consistently within a stack.[44]

Cut flowers

Cut flowers are living tissues and thus their life declines after harvesting due to the physiological changes in respiration, transpiration and biosynthesis, and microbial deterioration during storage, transportation and display.[45] Post–harvest procedures such as low temperature storage have been found to be effective in extending the vase life of cut–flower. Brosnan & Sun[45] and Sun & Brosnan[46] showed that vacuum cooling is effective method to extending the vase life of cut daffodils and cut lily flowers.

Bakery products

In the bakery industry, it is imperative to cool baked products prior to packaging to avoid in–pack vapour condensation. Vacuum cooling is an effective rapid cooling method for a wide range of baked products such as bread rolls, crusty breads, sausage rolls, pastries, meat pies, biscotti bread, cakes and baked biscuits.[47] Vacuum cooling is reported to cool baked products from 98°C to 30°C, and results in a weight loss of about 1% for every 10°C drop in temperature or (6.8% from 98°C to 30°C). In comparison, conventional air blast cooling results in a 3–5% weight loss depending on air velocity.[42]

Viscous food products

Viscous food products and components such as sauces, meat slurries, fruit concentrates are challenging to cool by mode of conduction or convection due to the high resistance to heat transfer caused by the high viscosity. Since water is a key component in these products, evaporation of a part of the water could aid in cooling.

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Vacuum cooling has been successfully employed for cooling these products.[48]

Cooked meats

Under vacuum conditions cooked meat can be cooled from 70–74°C to 4°C in 1–2.5h, when compared to 9.4–11.7h for air blast cooling,[49] 12–14h for slow air cooling[49] and 5–14.3h for water immersion cooling.[50] Sensory analysis showed that panellists preferred vacuum cooled cooked beef because of the natural and intense flavour.[44,50] However, no significant difference was found between products cooled by vacuum cooling and traditional cooling in terms of overall flavour, texture and acceptability.[49,50] The physico–thermal properties of the vacuum cooled products had low thermal conductivity, thermal diffusivity, specific heat capacity and; apparent density attributed to low moisture content.[36]

Process modelling

Mathematical models to describe the vacuum cooling process are expected to aid in process design and optimisation. Research on modelling of vacuum cooling process is sparsely reported.[51] Few models developed for vacuum cooling of liquid food, primarily concentrated on predicting the transient temperature of liquid food and vacuum pressure inside the chamber.[48] The models were developed based on the assumption that evaporation rate of water was relative to the mass transfer coefficient, mass transfer area and pressure difference between the saturated vapour above liquid surface and the bottom of the vessel. Dostal & Petera[52] modified existing models assuming a thermodynamic equilibrium between gas and liquid phases and unsteady heat and mass transfer resistances. During the mathematical modelling of vacuum cooling of cooked meats, Wang & Sun[43,53] developed a model for the vacuum cooling process consisting of two coupled sub models, one for defining the vacuum cooling system and the other for analyzing heat and mass transfer process during cooling of cooked meats.

The first sub–model developed involved analysing the mass conservation of the air and vapour in the system.[53] The internal air pressure difference was attributed to the pressure of entrance air and air evacuated by the vacuum pump, while vapour generated from water evaporation in the product, vapour removed by the condenser as well as evacuated by the vacuum pump were considered to contribute to total vapour pressure variation.

In the second sub–model,[43] the heat transfer equation considered was a three–dimensional transient heat conduction problem with inner heat generation. The mass transfer process was treated as hydrodynamic vapour movement through inner pore spaces of the solid product with inner vapour generation. The two sub–models were combined and solved by using finite element method to predict the transient product temperature profile and internal chamber pressure, cooling loss, etc. Experimental verification confirmed that the prediction from the models were relative with experimental measurement.[35,43,53]

Advantages and disadvantages of vacuum cooling

McDonald & Sun[44] stated that the major advantage of vacuum cooling over other conventional cooling techniques was the short time required to cool a food product to a given temperature. Vacuum cooling has been established as a faster cooling process than conventional methods such as air blast, immersion and still air cooling. The fast rate is attributed to the latent heat involved in evaporation of surface water.[44] Another advantage of vacuum cooling reported is in its ability to allow uniform cooling of even tightly wrapped products owing to the effect within the whole of the product.[54] Also, vacuum cooling can be applied on washed product, and also used to remove the surplus moisture present on the surface of the product.[55]

McDonald & Sun[44] discussed the major disadvantage of vacuum cooling as the loss of weight due to moisture removal. The high equipment cost for vacuum cooling process, limits the type of products suited to this method (large surface area products), and the additional cold store requirement to keep product cool are disadvantageous.[56]

Vacuum drying

Thirugnanasambandham & Sivakumar,[57] applied vacuum drying process and studied the moisture removal, vitamin C content and total dietary fibre in coriander leaves during the drying process. Experiments were conducted as per the Box–Behnken design (BBD) and Response Surface Methodology (RSM) was applied to estimate and optimize the three key drying parameters, namely temperature, loading rate and the level of vacuum. The optimal conditions were found to be temperature of 75°C, loading rate of 0.63kg/m^2 and vacuum of 28mmHg.

Watanawanyoo & Chaitep,[58] studied the possibility of applying a vacuum drying system operated by water ejector pump to dry agricultural products commercially. They examined the influence of operating variables on the performance of the water ejector pump to identify the best point for drying. The influence of four dependent variables, i.e. vacuum, temperature, water pressure and quantity of make–up air was evaluated on the drying performance.

Sumic et al.[59] optimized the vacuum–drying process for frozen sour cherries with a view to preserve the “phytochemicals” and textural attributes. The range of parameters evaluated includes temperature (46–74°C) and vacuum (17–583mbar). The quality of the dried sour cherry was quantified in terms of the total solids, water activity, total phenolics, vitamin C, antioxidant activity, anthocyanin content, total colour change and firmness. The optimised conditions obtained in the study for vacuum drying of sour cherry were 54.03°C and 148.16mbar.

Bazyma et al.[60] theoretically and experimentally evaluated low–temperature vacuum drying processes for floral agriculture products. They combined the system with Infrared ceramic radiators and analysed the efficient radiator power to provide optimal drying conditions in terms of the drying period, energy consumed and quality of the dried product. Jena & Das[61] applied a laboratory scale vacuum dryer to dry coconut press cake to a moisture content less than 0.02% (dry basis). The drying characteristics of the process were also examined under varying thickness of the press cake (2, 3 and 4mm) and vacuum chamber plate temperature (65, 70 and 75°C) at 65mmHg absolute pressure.

Jaya & Das[62] vacuum dried mango pulp spread to varying thickness (2, 3 and 4mm) and chamber plate temperature (65, 70, and 75°C) under 30–50mm of mercury absolute pressure. A model based on moisture diffusivity was applied and a close agreement between predicted and experimental moisture content of the pulp was observed. It was recommended that vacuum drying of coconut press cake should be carried at maximum pulp thickness of 2.6mm and vacuum chamber plate temperature of 72.3°C.

Microwave Vacuum Drying (MWV Drying)

Drying is amongst the earliest applications in food processing for which vacuum was adopted and extensively reviewed in literature. The combination of two novel technologies, viz., microwave and vacuum has been also been reported. Microwave–vacuum drying has been examined as a prospective method for obtaining high–quality dried foodstuffs, including fruits, vegetables and grains.[63–65] It combines the advantages of both vacuum drying and microwave drying resulting in higher drying rates, lower temperatures (25–50°C) and uniform energy efficiency compared to other drying methods.[66] The input energy dissipates in the product, and the moisture within adjusts automatically. The combined process results in superior sensory quality including aroma and flavour profile and preservation of color in dried products. Cui et al.[67] used MWV drying to obtaining high–quality dried honey. Liquid honey was first heated and then dehydrated in a MWV dryer to a final moisture content less than 2.5% within 10 min. The drying curves and the temperature changes of samples were established during MWV drying at different vacuum pressure levels, microwave power and sample thicknesses.

Drouzas et al.[68] developed a laboratory microwave vacuum drier to conduct kinetic experiments drying of model fruit gels simulating orange juice concentrate. The system was operated in the vacuum range of 30±50 mbar and microwave power of 640–710W. The distribution of the electromagnetic field was determined from the drying rate of samples, placed at 5 different locations.

Drouzas et al.[69] applied microwave vacuum dying to banana slices and reported that this method of drying was preferable over conventional dying techniques. The drying standardised introduced pulse generated microwave power in banana samples. Mousa & Farid[70] studied vacuum drying on banana slices in a domestic microwave oven. The results indicated that banana temperature increased uniformly and rapidly to the saturation water vapour temperature equivalent to the vacuum used followed by a slow rise until most of the free moisture was removed. The thermal and drying efficiencies were found to fall from initial values of 100% to as low as 30–40% towards the end of drying. Both efficiencies were found to surge with the use of vacuum, especially at low moisture content.[71]

Yongsawatdigul & Gunasekaran[72] investigated MWV drying on cranberries pre–treated for 24h before drying in a laboratory–scale microwave–vacuum dryer operating in continuous or pulsed mode. In the continuous mode, two levels of microwave power (250, 500W) in combination with two levels of absolute pressure (5.33, 10.67kPa) were applied. Microwave power of 250W and two levels of pressure (5.33, 10.67kPa) with two levels of power–on time (30, 60s) and three levels of power–off time (60, 90, 150s) were used in the pulsed mode.

Microwave application in combination with vacuum is reported to produce heating rates about 20–30times higher than conventional freeze–drying. Commercially, microwave drying is ranked between spray drying and freeze–drying. The capital investment involved for MWV drying is higher (about 60%) than that of freeze drying equipment, but the operating cost is reported to be reduced by a factor of 3 to 4, because of the higher solids content of the concentrate.[73,74]

Vacuum packaging

In addition to processing applications, vacuum has also been adopted during packaging of food products to extend its shelf life. The process involved evacuating the headspace from the package and sealing the package in a leak–proof and airtight manner. The technique has been adopted for a wide variety of food products including whole, cut and processed items such as meat. Stamatis & Arkoudelos[75] established the beneficial effect of vacuum[76] and modified atmospheres packaging (50% CO_2/50% N_2) initial head–spaces in comparison with atmospheric air packages on the microbiological, physicochemical and sensory variations of chub mackerel (*Scombercoliasjaponicus*) stored at 3 and 6°C. Frangos et al.[77] assessed the effect of vacuum packaging in combination with other ingredients such as salt, oregano, essential oil on fresh rainbow trout fillets stored at 4°C. The treatments were evaluated in terms of the chemical and microbial quality of fresh product and sensory evaluation of the cooked trout. The study established the efficacy of vacuum packaging in extending the shelf life of the trout samples while preserving the freshness of the produce.

Hansen et al.[78] examined the effect of vacuum packaging in combination with a CO_2 emitter pad on the shelf life of cod loins (farmed Atlantic cod, *Gadusmorhua*). The packaged samples were stored at 2°C and drawn at an interval of 15days and the treatment effects were evaluated for bacterial growth, microbiota and sensory quality. The study observed that vacuum packaging had a positive effect on the shelf life of the samples.[79]

Narasimha & Sachindra[80] used vacuum packaging (VP) and modified atmospheric packaging (MAP) to preserve meat and poultry products. MAP was observed to retain the meat colour better than in VP establishing the necessity of oxygen to project the right colour of myoglobin in meat. The observation was further confirmed since it was reported that the meat colour was recovered when removed from VP packets and exposed to air. The microbial profiles for products packed in using MAP and VP were not significantly different.[81–90]

Conclusion

Vacuum technology has been applied in conjunction with food processing unit operations such as frying, cooling, drying and packaging to reap several benefits such as improved product quality and nutritive value, extended shelf life and faster processing. The adoption of vacuum technology is limited by the additional capital cost and requirement for leak proof systems. The future direction for the technology includes exploration of further avenues for its application and developments to make the vacuum systems economical and more energy efficient. Such development would result in widespread adoption of the technology for sustainable and economically viable processing applications.

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Conflict of interest

The author declares that there is none of the conflicts.

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