REVIEW PAPER

Minimal processing of food: sous vide technique

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Abstract

"Zero" (unprocessed) to minimally processed food has become increasingly popular due to growing consumer attitudes towards the origin of unprocessed and minimally processed foods. Minimal processing techniques have been shown to be highly effective in prolonging shelf life and improving product quality and safety. One of the mild preservation techniques and an example of a "hurdle concept" is sous vide, which focuses on minimal heat treatment of foods, under vacuum. The sous vide cooking conditions are quite different to those employed in traditional cooking methods, or those adopted by the catering and food industries. As a combination of vacuum and precise cooking, on one hand, and healthy diets with new food experiences on the other, sous vide is rapidly gaining popularity. This technique is applied worldwide, in restaurants, catering, industrial production, and households. Microbiological safety of sous vide products depends on time and temperature control during cooking process, rapid cooling after processing, and temperature control during storage. Furthermore, high microbiological quality of the raw ingredients, additives, as well as good production process hygiene, are essential in production of microbiologically stable and safe sous vide products. Due to application of relatively low temperature, if present, spore formers will not be inactivated by the treatment. Therefore, to significantly reduce spore formers or spoilage/harmful bacteria it is necessary to utilise only the raw material of best quality. Some bacteria, though non-spore formers like *Listeria monocytogenes, Enterococcus faecalis* or *Staphylococcus aureus* may pose safety problem due to their specific cell wall structure. Sous vide technique can successfully be combined with non-thermal methods to control existing microflora, especially pathogenic microorganisms. This overview presents the types of methods, cooking conditions, and qualitative characteristics of typical sous vide foods (made from meat, seafood, vegetables, and other raw materials). The advantages and disadvantages of sous vide cooking which have an impact on nutritional and sensory quality and food safety are presented.

Keywords: minimal processing, "hurdles", sous vide, food, food safety.

Introduction

New technological innovations in the food industry shifted habits of today's consumers. Due to these restrictions, it is not so easy for manufacturers to use traditional combinations of methods to preserve food, which is why new, milder methods, such as minimal processing, have been developed.

Minimal processing involves a series of techniques tailored to a specific raw material/food that preserve the original quality while ensuring safety. In the modern approach to preservation processes and procedures, the concept based on the effect of a so-called "hurdle" and the application of technology

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is becoming increasingly important and is referred to as "hurdle technology" (Leistner, 1995; Lovrić, 2003). The hurdles concept means the application of the combined action of several physical, chemical or other parameters as a series of process barriers that microorganisms cannot "cross", thus achieving a preserving effect. The higher the barrier, the harder it is for microorganisms to overcome it. With this combination, each individual hurdle in the series can be performed in significantly milder conditions than when it is used on its own (Lovrić, 2003). One of the mild preservation techniques and an example of a hurdle system is sous vide.

Sous vide (French for "under vacuum") is a technique for cooking (processing) food in restaurants, at home, in catering and in industry. It is a controlled thermal and temporal treatment of raw materials or partially cooked, prepared food in a heat vacuumed packing, immersed in a water bath or placed in a hot steam oven (Schellekens, 1996).

The technique dates back to the 1970s, when a French chef Georges Pralus worked with plastic film in order to minimise the cooking loss of pâté de foie-gras and founded the beginnings of the sous vide cooking (Brugalla, 2019). Another French pioneer, Bruno Goussault, a biochemist and microbiologist, developed the parameters of cooking times and temperatures. Although chefs in the high-end restaurants have been using sous vide since the 70s, thanks to chef Gérard Bertholon in the 2000s, the technique became widely known (Keller, 2008). In the late 2000s and early 2010s, sous vide started being popular in restaurants and households (Baldwin, 2012). Today, this term implies a much wider range of products compared to early definitions. In contrast to a fancy technique for top restaurants, sous vide today is rapidly gaining popularity and is accepted by the mass production food sector, as well as home consumers.

Recent research combines sous vide technology with additives, novel and innovative (non-thermal) technologies that have a positive impact on both quality and safety (Picouet et al., 2011; Dewitt and Oliveira, 2016; Llave et al., 2016.; Cropotova et al., 2019; Pongsetkul et al., 2023.; Russo et al., 2023). In addition, interesting studies have investigated sous vide method in combination with modified atmosphere (Abel et al., 2019), irradiation (Dogruyol and Mol, 2016), high-pressure processing (Kirse et al., 2017), microwaves (Renna et al., 2017), addition of essential oils (Gouveia et al., 2016) and plant additives, e.g., tea leaf and apple peel powder (Juneja et al., 2009), to control pathogenic microorganisms.

Scientific research over the past few years has been well-established, and explored the physical, biochemical properties and sensory acceptability of sous vide food, but microbiological and safety aspect is still to be fully considered and remains a concern.

Sous vide method: food preparation and processing

The best description of sous vide technique would be a combination of vacuum and precision cooking. An exact definition is difficult, because sous vide can be used to describe processes in a narrower

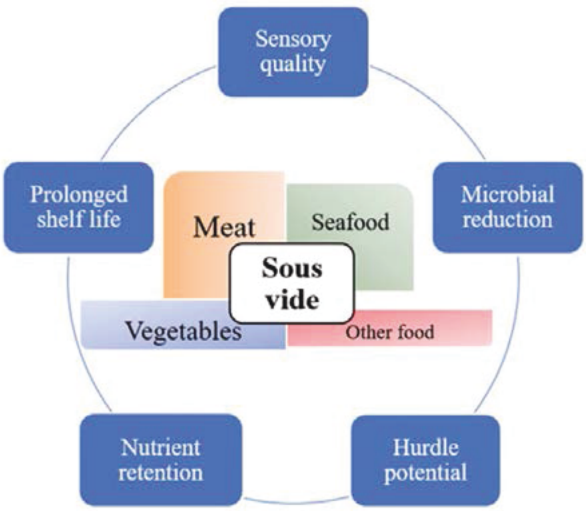

Figure 1 Application and advantages of sous vide technique

or broader sense, in regards to application.

Cook-hold or *cook-serve* technique commonly used by gourmet chefs consists of preparation, vacuum packaging of food and treatment in the cooking chamber. After cooking, food is removed and served or finished (grill or pan).

Other form is *cook-chill* or *cook-freeze*, in which, after the food is prepared, vacuum packaged and partially cooked, it is rapidly cooled, and then chilled (or frozen) until use. The products are then finished, reheated or rethermalized, to complete the cooking process, and served.

The technique commonly used by manufacturers of ready meals implies preparation, vacuum packaging of raw or blanched food, pasteurisation, blast chilling, and storage of the food in the refrigerator or freezer, which customers reheat and consume.

Sous vide is a part of LTLT processing (low temperature long time). The method consists in heating the product to a low endpoint temperature (60 °C or less) over a longer period. Product is kept isothermally from hours to even days (Hernandez, 2018). Temperature controllability of sous vide cooking offers more choices in term of "doneness" and texture compared to conventional cooking methods, which improves shelf life and offers the possibility of preserving the sensory properties and nutritional quality of food (Amoroso et al., 2018). Depending on the raw material, food preparation begins with different operations, which include sorting, washing, cutting, peeling, etc. In the case of vegetables, most species must be blanched (conditions depend on portion size); some raw materials must be preserved from browning, etc. Ingredients are added, raw or previously prepared, into product. For example, meat is often marinated (fruit juice, buttermilk, vinegar, wine, etc.), tenderised, or brined. Brining is common for pork and poultry in modern sous vide. The brine dissolves part of the muscle fiber structure, prevents coagulation and meat can absorb 10-25 % of its weight (in some cases also flavourings from herbs and spices).

Mixing and preparation are followed by packaging (Graiver et al., 2006; Baldwin, 2012; Carlin, 2014). Plastic polymers must be resistant to temperature and pressure, have sufficient mechanical strength, and limited migration of residues into food (Schellekens, 1996). Inert materials are recommended for sous vide packaging (polyethylene, ethylene vinyl alcohol, polyamide, and other multi-laminate materials) as they have no harmful effects on the colour and have low oxygen and moisture permeability.

Vacuum sealing enables efficient heat transfer and extends shelf life of food (for cook-chill or cook-freeze techniques). It also inhibits oxidation-induced off-flavours and prevents evaporation losses of volatiles (Church and Parsons, 2000). „Cook-in-bag" system is rapidly gaining popularity because it minimises the loss of minerals and vitamins most vulnerable to high temperatures like vitamin B1, B2, and ascorbic acid (Creed, 1995; Aviles et al., 2020). Da Silva et al. (2017) compared the sous vide method with heating in boiling water. The results showed that the sous vide method provides higher bioavailability of magnesium, copper, calcium, and iron from beef liver, except for potassium - both methods have equivalent values.

After the air has been removed from the food packaging and a vacuum of varying degrees has been created, the packaging is quickly thermally sealed to prevent loss of the vacuum and remains impermeable. Regarding the degree of vacuum, high pressure is not recommended for fish fillets and some vegetable materials as it damages the tissue structure. The residual pressure in the packaging is typically 100-120 mbar, whereas for firm and physically resistant food ingredients, such as root vegetables, it can be up to 10-15 mbar (Schellekens, 1996; Kilibarda et al., 2018).

After sealing, the vacuum-sealed bag is completely immersed in a water bath or placed in a hot steam oven and then cooked (Carlin, 2014). According to application, sous vide machines were divided into commercial and residential, and by type, immersion circulators and sous vide ovens. Typical temperatures around 50-75 °C are used for meat and seafood processing, and maintained for several hours to 48 hours, but application to vegetables requires temperatures closer to 90-100 °C (in some cases, only a few minutes) (Kilibarda et al., 2018).

After processing, food is served or in the case of cool storage, the food products are firstly quickly cooled at the range of 1-8 °C. An ice-cold water bath and direct chilling are both more effective than blast chilling. Storage of refrigerated or frozen food follows until the time of serving, regardless of whether it refers to restaurants or domestic use (Stankov et al., 2020).

Regeneration (brought back to serving temperature) means that the food is reheated and

kept at temperature (at least 70 °C) in the centre until serving. With the conventional cook-chill technique, the dish must be reheated too. No more than five minutes should elapse between reheating and serving the food (Singh et al., 2023).
Serving food can provide a "temporal buffer" and flexibility in meal offerings, as opposed to the limited stability of traditional products (Jang and Lee, 2005).

Sous vide: animal products
Meat and meat products

The sous vide technique is widely used in the processing of meat and meat products and its application has made this method popular worldwide (Ruiz-Carrascal et al., 2019). Thanks to the precise temperature control, meat, for example, can be cooked evenly for each piece, unlike conventional cooking methods (Stringer at al., 2012). Since conventional processing was not adapted to today's immature meat, the products are often dry, tasteless and lacking in flavour, which is not the case with the sous vide method (Baldwin, 2021). Sous vide provides cooking of almost any cut of meat so that it is moist, tender, and flavourful. Sous vide foods generally contain no preservatives (Stringer and Metris, 2018). What all applications have in common, however, is the use of plastic bags, which enable heat transfer and eliminate the risk of microbial contamination during preparation, storage and handling (Díaz et al., 2008; Stringer and Metris, 2018). Packaging also prevents the loss of volatile aromatic compounds and water, which improves the sensory properties and helps make the meat juicy and tender.

Several studies (Roldán et al., 2013; Falowo et al., 2017; Church and Parsons, 2000; Kurp et al., 2022, and others) carried out on lamb, beef, chicken, and pork meat noticed that cooking at 60 °C or higher improved meat tenderness, and contributed to juiciness, fragility, taste, and more. Scientific and other studies usually focus on tenderness as one of the most important taste characteristics that significantly influences consumer satisfaction and purchase likelihood (Naqvi et al. 2021). Tenderisation is mainly attributed to the reduced denaturation of myofibrillar proteins at lower temperatures and the weakening of connective tissue due to the dissolution of collagen. Naqvi et al. (2021) demonstrated a significant correlation between the age of beef with the myofibrillar fragmentation index and collagen dissolution during cooking. Understanding the mechanisms associated with the sous vide process offers a potential advantage for better marketing of lower quality beef, particularly from older animals. Sous vide achieved extraordinary results regarding the degree of softness of tough pieces of meat, which is related to very specific combinations of LTLT conditions (Ruiz-Carrascal et al., 2019). Furthermore, cooking at low temperatures is less sensitive to changes in time of preparation, which is important during food service (Mortensen et al., 2012). For safety reasons, the lowest processing temperature of meat products should be 55 °C, as this is the lowest practical temperature for the denaturation of collagen (Baldwin, 2012; Roldán et al., 2015). Chefs include LTLT processing for beef, pork or lamb in temperature range of 58 to 63 °C (10-48 h), while common temperatures for catering and ready to eat meals reach between 75 to 80 °C (Garcia-Segovia et al., 2007; Pulgar et al., 2012; Ruiz-Carrascal et al., 2013). According to some authors, LTLT conditions also increase the activity of proteolytic enzymes in meat, free amino acids release, the formation of volatile compounds (Roldán et al., 2015) and a further improvement in meat tenderness (Hernandez et al., 2018).

The recommended temperatures for cooking poultry are from 55 °C to 80 °C. These are the lowest temperatures used for duck breast, which is traditionally served still pink in the middle. Traditionally, light poultry meat is cooked well-done (70 °C to 80 °C) because of food safety.

Chicken and turkey breast can be cooked to a medium degree of doneness (60 °C to 65 °C) and pasteurised for safety. An additional problem is that some of the heat treatments used to cook chicken breast cause the meat to retain a pink colour (Baldwin, 2021).

According to the previous findings of Stringer et al. (2012), the recommended average cooking temperature for red meat was 60 °C with a cooking time of 4 hours (or more). According to Stringer and Metris (2018), average cooking temperature for poultry is 63.5 °C, for egg products 64.5 °C and for dairy products 82 °C. The highest average temperatures of 85 °C were used for vegetables.

Precision cooking in sous vide provides uniform and consistent texture and colour of beef (Mortensen et al., 2012) and promotes higher water retention, maximising weigh yield (Juneja and Snyder, 2007). Compared to other meats, beef needs to be heat-treated for longer, although a longer duration at an appropriate temperature has less impact on the water content of the meat (Chotigavin et al., 2021; Latoch et al., 2023). Higher water retention rates ensure that the nutritional quality of sous vide meat is maintained and that vitamins, minerals and unsaturated fatty acids are better preserved than with other methods (Falowo et al., 2017; Ayub and Ahmad, 2019; Modzelewska-Kapituła et al., 2019; Cui et al., 2021).

Individual anatomical parts of animals and their composition (content of fats and proteins) influence the choice of sous vide parameters (Wang et al., 2004). Application of sous vide in poultry is interesting due to its high-water content and lower level of collagen (Stankov et al., 2000). When heated in the presence of water and steam, the composition of the meat changes considerably. At relatively low temperatures and slow heating of the muscle cells, the water in the sarcoplasm is retained and there is prolonged dissolution of the binding proteins and slight coagulation of the proteins.

The sarcoplasmic soluble proteins consist of about 50 components, mainly enzymes and myoglobin, which swell strongly at 40-50 °C, increase their surface area and turn into a gel-like sponge (which retains large amounts of cell sap). Sous vide cooking improves the taste of the meat as it prevents the loss of volatile components and water, and inhibits the aftertaste caused by the oxidative reactions of proteins and fats.

These changes significantly improve the juiciness, colour and protein digestibility of meat (Latoch et al., 2023). The aggregation and gelation of sarcoplasmic proteins finishes at about 60 °C, and largely determines the tenderness of meat. Above 60 °C, the muscle fibers and connective tissue begin to shrink longitudinally, which leads to a loss of water. Significant changes in the structure of muscle proteins are observed at temperatures above 65 °C, when the collagen on the surface of the muscle fibers begins to break down. Heat treatment destabilizes the triple helix of collagen filaments, resulting in helix-to-helix spiralling and conversion to soluble gelatin (Gómez-Guillén et al., 2002; Hashim et al., 2015). The degree of collagen conversion into gelatin is related to extraction process, as a function of temperature, pH and extraction time (Gómez-Guillén et al., 2011). Elastin fibers are not denatured and their change is not decisive for the culinary suitability of the meat (Baldwin, 2012).

Many studies (Pulgar et al., 2012; Roldán et al., 2013; Dominguez-Hernandez et al., 2018; Abel et al., 2019, Brugalla, 2019; Ruiz-Carrascal et al., 2019, etc.) have shown that sous vide improves the quality of meat consumption by improving sensory properties, texture parameters, nutritional properties and digestibility, and prolong shelf life.

Jang and Lee (2005) compared the conventional preparation of seasoned beef with the sous vide method. The sous vide packaging effectively protected the beef from microbial, physical and qualitative deterioration. The shelf life based on sensory evaluation changed when stored at 3 and 10 °C and was around 12 days for the products prepared using the sous vide method, while the microbiological stability was at least 42 and 24 days respectively. The shelf life of the conventional products was 7 and 3 days at 3 and 10 °C, respectively. Wang et al. (2004) investigated the oxidative stability and shelf life and showed that sous vide cooking at 74 °C and storage at 2 °C prevent lipid oxidation of chicken products. Oz and Zikirov (2015) investigated the effect of the sous vide (at 75, 85 or 95 °C for 2 or 4 hours) on the formation of heterocyclic aromatic amines (HCA) in beef chops. At the same temperature, HCA in the sous vide cooked samples increased with increasing cooking time. Compared to boiled and pan-fried beef, the highest HCA was found in the pan-fried samples.

Eggs

Control of sous vide cooking makes it possible to control both fast and slow changes. In eggs, it is the change of tightly bundled proteins that unfolds during denaturation and causes the egg white or yolk to thicken and gel (Baldwin, 2012). The fast changes occur when the temperature of the food exceeds a certain threshold. For example, a hen's egg with shell was heated until the temperature is equalized (for 30-60 minutes): at 61.5 °C the protein conalbumin denatures and causes the egg white to form a loose gel; at 64.5 °C the protein livetin denatures and causes the egg yolk to form a tender gel; at 70 °C the protein ovomucoid denatures and causes the egg white to form a firm gel (the egg yolk also coagulates around this temperature) and at 84.5 °C the protein ovalbumin denatures and causes the egg white to become rubbery.

Sous vide: Seafood

Nowadays, the demand for fresh and lightly processed seafood that is safe to eat is continuously increasing (Stankov et al., 2020). Seafood, whether fresh fish or other organisms, is highly perishable and poses a challenge to meeting market demand (Russo et al., 2023). Seafood retail requires a combination of sous vide processes with other processing steps to make it safe and shelf-stable while ensuring high quality.

Chemical composition, primarily to high water content, neutral pH, high accumulation of microorganisms on surfaces and the presence of autolytic enzymes of fish meat are a prerequisite for the development of many psychrophilic and mesophilic microorganisms (DeWitt and Oliveira, 2016). For this reason, fish as a raw material must be kept fresh under appropriate conditions, with good sanitary and hygienic indicators (Picouet et al., 2011).

The culinary processing of seafood using the sous vide method can expand assortment on the restaurant menu. The preparation and heat treatment processes of seafood differ from those of other foods and must be carried out with precision. In restaurants, fish is prepared by pre-treatment (cleaning of scales, innards, cutting). For other seafood delicacies, the pre-treatment is specific and depends on the anatomical characteristics of each species. In the sous vide cooking of fish, the most commonly used treatment temperature is 46-49 °C (Stankov et al., 2020).

The proposed sous vide process for fresh salmon, for example, is a particularly short-term treatment at low temperatures that results in a high-risk product. Vacuum bags with salmon are immersed in a 50 °C water bath for the time it takes to reach a core temperature of 40 °C. Products must be consumed immediately after cooking and cannot be stored refrigerated (Picouet et al., 2011).

The non-thermal high-pressure process (HPP) is combined with the sous vide process to pasteurise delicate products and use them as ready meals. The HPP process (over 310 MPa with a holding time of 300 s) was used 1-2 hours after sous vide cooking of salmon fillets. Obtained results suggest an increase of shelf life of sous vide cooked salmon up to 6 days for the total viable counts and 8 days for the *Enterobacteriaceae* (Picouet et al., 2011). Almeida et al. (2017) investigated the shelf life by monitoring the physicochemical, microbiological and sensory properties of sous vide tambaqui (*Colossoma macropomum*) fillets prepared with soy sauce and basil sauce (65 °C, 12.5 min) and kept refrigerated at 1 °C. Fillets marinated in soy sauce could be kept for 49 days, whereas fillets marinated in basil sauce could be kept for 42 days. Pongesetkul et al. (2023) investigated the effects of different sous vide cooking conditions (50-60 °C, 30-60 min) on the physicochemical properties, protein degradation and sensory acceptability of tilapia fillet (*Oreochromis niloticus*). The optimal conditions for tilapia meat were 60 °C for 45 min, as they showed the best results for the textural properties and sensory acceptability of the fillet. The study utilised SR-FTIR technique to provide essential information for a better understanding of changes in biomolecule related to the textural properties of fish products.

Combining the sous vide technique, low storage temperatures and processing steps such as packaging technologies (e.g. modified atmosphere packaging) to extend the shelf life of seafood is promising. Salmon fillets treated by sous vide cooking (45 °C for 15 minutes, 55 °C for 18 minutes, 65 °C for 21 minutes) were stored under modified atmosphere (60 % CO_2 in equilibrium with N_2) with/without stabilisation by soluble gas (100 % CO_2) at 4 °C for up to 24 days. The results showed that sous vide processing with soluble gas stabilisation and low temperatures had a synergistic effect and improved shelf life by inhibiting bacterial growth, especially of *Listeria* spp. (Abel et al., 2019).

The sous vide treatment of squid, octopus, abalone and clams is one of the greatest challenges today, as cooking must be done very slowly and at low temperatures to prevent the muscle fibers from hardening. The result is soft, tender products, while the plastic packaging and vacuum conditions prevent the loss of flavour (Cui et al., 2020; Zavadlav et al., 2020).

Sous vide: vegetables

Sous vide technique in vegetable processing is widely applicable and enables precise cooking for optimum colour, aroma, taste and texture, with minimum nutritional losses (Amoroso et al., 2018; Pooja and Chethan, 2022).

The sous vide conditions should be selected individually for each vegetable to guarantee the desired sensory and other properties of the products. For example, chefs cook starchy vegetables at 75 to 90 °C, other vegetables at 80 to 95 °C, and beans and pulses at 90 to 95 °C (Baldwin, 2021). Otherwise, the thermal processing of plant tissues (82-85 °C) leads to depolymerization reactions of the polysaccharide pectin, which begins to dissolve, resulting in a deterioration of the texture (Fraeye et al., 2007).

Sous vide packaging prevents vegetables from coming into direct contact with oxygen, which limits the oxidation of plant pigments and preserves the colour (Kilibarda et al., 2018.). In addition, the release of some components (amino acids, organic acids, etc.) is reduced, which also affects the taste. In addition, the product contains more bioactive compounds with health-promoting and antioxidant properties (Czarnowska-Kujawska et al., 2023). The fact that water cannot penetrate the intracellular structure of vegetables from the outside means that the product has a longer shelf life. In terms of colour stability, Patras et al. (2010) showed a colour reduction (12 %) in carrots prepared sous vide (90 °C, 10 min), while the colour reduction in samples cooked in water (up to a core temperature of 70 °C) was 30 % compared to fresh carrot slices. For starchy vegetables (beans, peas, lentils, corn, potatoes, etc.), sous vide cooking causes the starch granules to swell and gelatinize, resulting in a uniform cooking time (Baldwin, 2012). Iborra-Bernad et al. (2014) evaluated the changes in texture, colour and anthocyanin content of red cabbage cooked using the traditional and sous vide methods. The results are based on an experimental design (RSM) combining instrumental and sensory analyses. The sous vide treatment improved the sensory and nutritional quality of the red cabbage and is recommended for gastronomy, with the same budget invested in raw materials. Sous vide cooked vegetables (beets, green beans and broccoli) are no less valuable as a source of minerals for the daily diet than raw vegetables, while improving the sensory properties of the processed food (Czarnowska-Kujawska et al., 2023).

Sous vide: other foods

Sous vide cooking of fruit is an excellent way to tenderise it without losing vitamins and minerals. The use of sous vide cooking for fruit focuses on the treatment of apples and pears (Baldwin, 2012). All fruits can be cooked sous vide, but the cooking time and temperature depend on the type, firmness and ripeness of the fruit. Pectin is broken down more slowly than the starch cells, making the fruit more tender and giving it a unique texture.

The sous vide method can be used to prepare crème anglaise, quark, ice cream and custard bases, sabayons and dulce de leche, etc.

Microbiological aspect of sous vide technique

Sous vide has, as mentioned previously, numerous advantages regarding nutritional and sensory quality of prepared food, as well as wide usage in restaurants, catering enterprises and ready-to-eat industry. Due to low temperature and minimal changes in proteins, it can be used for preparation of any meat cut into tender, juicy and tasty meal. Despite improvement of taste and nutritional value, microbiological safety of sous vide products is of outmost importance.

Since the temperature treatment is quite low, the major microbiological hazards linked to sous vide products are:

1. Oxygen free packaging is suitable environment for *Clostridium botulinum* type E growth, even at 3 °C storage temperature.
2. Low temperature growing pathogens e.g., *Listeria monocytogenes*, enterotoxigenic *Escherichia coli* and (especially) spore-formers like *Bacillus cereus* can survive applied temperature treatment and grow during low storage temperatures. Maintaining low temperature during transport and handling is of the outmost importance.
3. The packaging of prepared food must be thoroughly controlled since any leaks or tear of packaging material could enable growth of post-thermal processing contaminants (Nyati, 2000).

Microbiological safety of sous vide products depends on temperature control during the cooking process, rapid cooling after processing and control of temperature during storage (Kilibarda et al., 2018). Furthermore, high microbiological quality of the raw ingredients, seasoning, as well as good production process hygiene, are inevitable in production of microbiologically stable and safe food products.

Microbial population, significant for safety of sous vide product, can be summarized in four categories. The first one is vegetative bacteria usually inactivated by pasteurisation (non-spore-formers) and mostly unable to growth at low storage temperature (*E. coli, Salmonella* spp., *Vibrio, Staphylococcus aureus* and *Campylobacter*). Due to prolonged temperature activity during sous vide production vegetative cells are inactivated. The second category are non-spore-forms like *L. monocytogenes, Yersinia enterocolitica* and *Aeromonas* spp. sensitive to pasteurisation temperature although some cells can survive milder temperature regime. The above-mentioned bacteria pose a considerable safety problem, as they can grow at low temperatures during storage. Psychotrophic spore formers survive pasteurisation and grow during storage at low temperatures (non-proteolytic *C. botulinum*, psychrotrophic *B. cereus*). Specie of the fourth category are mesophilic spore-formers: proteolytic *C. botulinum*, mesophilic *B. cereus* and *C. perfringens* will survive temperature treatment although are unable to growth at low storage temperatures (Stringer and Metris, 2018).

Vacuum packaging of sous vide food provides oxygen free environment thus favourable conditions for growth, spoilage and possible toxin production of anaerobes. One of the most important biological hazards in sous vide production is *C. botulinum* type E since it (spore-former) survives pasteurization temperature and produces toxin at 3 °C (Lund and Peck, 2013). Since sous vide treatments involve prolonged pasteurisation temperature, vegetative cells are inactivated even at higher counts. Non-spore-formers, especially Gram-positive bacteria (thicker cell wall then Gram-negatives) can survive milder temperature treatment, and if psychrophiles like *L. monocytogenes* – often considered the most heat-resistant non-spore-former, are present in raw material, the growth at storage temperature is imminent. Since pasteurisation is a critical control point in inhibition of *Listeria* growth in sous vide food products, the European Union guidelines recommend the minimum heat treatment for sous vide pasteurisation is equivalent to heating at 70 °C for two minutes (Stringer and Metris, 2018).

The shelf life of sous vide cooked meats is estimated for 4-7 weeks depending on the product and processing conditions (Díaz et al., 2008). High water activity enables the growth of the main biological hazard *C. botulinum*, although other anaerobic sporulating organisms may appear, including *B. cereus* and *C. perfringens*. Reduction of total mesophilic aerobic bacteria during sous vide treatment at three temperatures (65, 70 or 75 °C) in turkey cutlets was observed by Biyikli et al. (2020) where higher temperature and longer time (20, 40 or 60 min) reduced counts ten to hundredfold. Additionally, total *Enterobacteriaceae* and *E. coli* were reduced from 3.22 $\log_{10}$ or 2.3 $\log_{10}$ respectively to <1$\log_{10}$ CFU/g. *Listeria* spp. was detected in raw sample and in sous vide sample treated at lower temperature (65°C) shortest time (20 min) while in all other samples was not detected. *Salmonella* spp. was not detected in any raw sample nor in sous vide treated sample. Haghighi et al. (2021) reduced total mesophilic aerobic, *Enterobacteriaceae* and psychrophilic aerobic counts below level of detection in chicken breasts sous vide treated at 60, 70 or 80 °C for 60, 90, 120 or 150 min, that remained the same during 21 days of storage at 4 °C. Wang et al. (2004) concluded that in tested chicken wings sous vide treatment retarded the growth of microorganisms within 7-week storage period. Similar results presented Roldán et al. (2013) in sous vide treated lamb loins where even shortest of the time-temperature combinations (60 °C/6 h) reduced almost all bacteria below level of detection. Bongiorno et al. (2018) in sous vide treated mussels observed only slightly increase of total bacterial counts after 30 days of storage at 3°C where sous vide treated samples had overall lower bacterial counts, even at 50th day of storage, compared to conventional treatment. Kim et al. (2002) observed comparable sensory quality of sous vide seasoned spinach soup to freshly prepared one. Coliforms, lactic acid bacteria and yeasts/moulds were not detected in the product that was microbiologically stable for 35 days at 3 °C (though only 10 days at 10 °C). At higher storage temperature, mild changes in the physical and chemical quality attributes were observed. Rinaldi et al. (2013) experimented with sous vide carrots and Brussel sprouts (30 min for carrots and 17 min for Brussel sprouts at 100 °C) and the results suggest better sensory quality for carrots (compared to conventional method) for short term storage (up to 5 days in the refrigerator) while sous vide Brussel sprouts, without pre-blanching step, showed a loss of firmness and green colour and an increase of yellow, as well as increasement of sulphur compounds (dimethyl disuflides and dimethyl trisulfides) associated with off flavour notes. The author emphasized the quality of the raw material as a critical step for the microbial survival of spoilage flora during sous vide treatment and storage.

Conclusions

The sous vide method offers numerous advantages over conventional cooking methods. In terms of product quality, the method makes it possible to achieve the desired textural properties and preserve vitamins, minerals, unsaturated fatty acids, bioactive components, etc. Sous vide cooking in vacuum packaging reduces the risk of contamination and extends shelf life of raw materials and food. In addition, the loss of nutrients is reduced and the degree of cooking can be reproduced and controlled. The precise control of temperature and time, as well as the anaerobic conditions, reduce the possibility of unpleasant aromas forming, the sensory properties are intensified and fats, proteins and pigments are protected from oxidative changes.

Sous vide cooking has some disadvantages. Perhaps the most important is that the Maillard reaction does not take place on the surface of meat that has been processed under LTLT (long-term low temperature) conditions. Sous vide cooked meat does not have a strong dark colour on the surface and no roasting aromas.

This method also requires special equipment and a longer processing time.

Since pathogenic microorganisms are often present in raw food, it is important that all necessary programmes (good manufacturing practice, good hygiene practice) and safety criteria based on the HACCP concept are strictly followed.

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Minimalno procesirana hrana: sous vide tehnika

Sažetak

„Zero“ (neprerađena) do minimalno procesirana hrana postaje sve popularnija kao posljedica rastućeg stava potrošača prema izvornosti neprerađene i minimalno procesirane hrane. Tehnike minimalnog procesiranja pokazale su se vrlo učinkovitima u produljenju roka trajanja i poboljšanju kvalitete i sigurnosti proizvoda. Jedna od blagih tehnika konzerviranja i primjer "koncepta prepreka" je sous vide, koji se fokusira na minimalnu termičku obradu namirnica. Kao kombinacija vakuuma i preciznog kuhanja, s jedne strane, te zdrave prehrane s novim prehrambenim iskustvima s druge, sous vide ubrzano stječe popularnost. Ova tehnika ima primjenu širom svijeta, u restoranima, ugostiteljstvu, industrijskoj proizvodnji i kućanstvima. Uvjeti sous vide kuhanja prilično su drugačiji od onih koji se koriste u tradicionalnim metodama kuhanja ili onih koje su usvojili ugostiteljstvo i prehrambena industrija. Mikrobiološka sigurnost sous vide proizvoda ovisi o kontroli vremena i temperature tijekom procesa kuhanja, brzom hlađenju nakon obrade i kontroli temperature tijekom skladištenja. Nadalje, visoka mikrobiološka kvaliteta sirovina, aditiva kao i dobra higijena proizvodnog procesa ključni su u proizvodnji mikrobiološki stabilnih i sigurnih sous vide proizvoda. Zbog primjene relativno niske temperature, ako su prisutne, sporogene bakterije neće biti inaktivirane obradom. Stoga je potrebno koristiti samo najkvalitetnije sirovine čime se značajno smanjuju štetni mikroorganizmi. Neke bakterije, iako ne stvaraju spore, poput *Listeria monocytogenes, Enterococcus faecalis* ili *Staphylococcus aureus*, mogu predstavljati sigurnosni problem zbog specifične strukture stanične stjenke. Sous vide tehnika može se uspješno kombinirati s netermičkim metodama za kontrolu postojeće mikroflore, posebice patogenih mikroorganizama. U ovom pregledu navedene su vrste metoda, uvjeti kuhanja i kvalitativne karakteristike tipične sous vide hrane i obroka (dobivenih od mesa, morskih plodova, povrća i drugih sirovina). Autori su predstavili prednosti i nedostatke sous vide kuhanja, koji utječu, između ostalog, na nutritivnu i senzorsku kvalitetu te sigurnost hrane.

Ključne riječi: minimalno procesiranje, “prepreke”, sous vide, hrana, sigurnost hrane

Minimale Verarbeitung von Lebensmitteln: Sous-Vide-Technik

Zusammenfassung

"Null" (unverarbeitete) bis minimal verarbeitete Lebensmittel erfreuen sich zunehmender Beliebtheit, da die Verbraucher immer mehr Wert auf die Herkunft unverarbeiteter und minimal verarbeiteter Lebensmittel legen. Minimale Verarbeitungstechniken haben sich als äußerst wirksam erwiesen, um die Haltbarkeit zu verlängern und die Produktqualität und -sicherheit zu verbessern. Eine der schonenden Konservierungstechniken und ein Beispiel für ein "Hürdenkonzept" ist das Sous-Vide-Verfahren, das sich auf eine minimale Wärmebehandlung von Lebensmitteln unter Vakuum konzentriert. Die Bedingungen beim Sous-Vide-Garen unterscheiden sich deutlich von denen traditioneller Garmethoden oder von denen, die in der Gastronomie und der Lebensmittelindustrie angewandt werden. Als Kombination aus Vakuum und präzisem Garen einerseits und gesunder Ernährung mit neuen Ernährungserfahrungen andererseits erfreut sich Sous-Vide immer größerer Beliebtheit. Diese Technik wird weltweit in Restaurants, im Catering, in der industriellen Produktion und in Haushalten eingesetzt. Die mikrobiologische Sicherheit von Sous-Vide-Produkten hängt von der Zeit- und Temperaturkontrolle während des Garprozesses, der schnellen Abkühlung nach der Verarbeitung und der Temperaturkontrolle während der Lagerung ab. Darüber hinaus sind eine hohe mikrobiologische Qualität der Roh- und Zusatzstoffe sowie eine gute Hygiene im Produktionsprozess für die Herstellung von mikrobiologisch stabilen und sicheren Sous-Vide-Produkten unerlässlich. Aufgrund der Anwendung relativ niedriger Temperaturen werden Sporenbildner, sofern vorhanden, durch die Behandlung nicht inaktiviert. Um Sporenbildner oder verderbliche/schädliche Bakterien signifikant zu reduzieren, ist es daher notwendig, nur Rohmaterial von bester Qualität zu verwenden. Einige Bakterien, die zwar keine Sporenbildner sind, wie *Listeria monocytogenes, Enterococcus faecalis* oder *Staphylococcus aureus*, können aufgrund ihrer spezifischen Zellwandstruktur ein Sicherheitsproblem darstellen. Die Sous-Vide-Technik kann erfolgreich mit nicht-thermischen Methoden kombiniert werden, um die vorhandene Mikroflora, insbesondere pathogene Mikroorganismen, zu kontrollieren. In diesem Überblick werden die Arten von Verfahren, die Garbedingungen und die qualitativen Merkmale typischer Sous-Vide-Lebensmittel (aus Fleisch, Meeresfrüchten, Gemüse und anderen Rohstoffen) vorgestellt. Die Vor- und Nachteile des Sous-Vide-Garens, die sich auf die ernährungsphysiologische und sensorische Qualität und die Lebensmittelsicherheit auswirken, werden vorgestellt.

Schlüsselwörter: minimale Verarbeitung, "Hürden", Sous-Vide, Lebensmittel, Lebensmittelsicherheit

Procesamiento mínimo de alimentos: técnica de sous vide

Resumen

Los alimentos "cero" (no procesados) o mínimamente procesados se han vuelto cada vez más populares debido a las crecientes actitudes de los consumidores hacia el origen de los alimentos no procesados y mínimamente procesados. Se ha demostrado que las técnicas de procesamiento mínimo son altamente efectivas para prolongar la vida útil y mejorar la calidad y seguridad del producto. Una de las técnicas de conservación suave y un ejemplo del "concepto de obstáculo" es el sous vide, que se centra en el tratamiento mínimo de calor de los alimentos. Las condiciones de cocción sous vide son bastante diferentes de las empleadas en los métodos de cocción tradicionales o los adoptados por la industria alimentaria y la de la restauración. Como una combinación de vacío y cocción precisa, por un lado, y dietas saludables con nuevas experiencias alimentarias por el otro, el sous vide está ganando rápidamente popularidad. Esta técnica se aplica en todo el mundo, en restaurantes, catering, producción industrial y hogares. La seguridad microbiológica de los productos sous vide depende del control de tiempo y temperatura durante el proceso de cocción, el enfriamiento rápido después del procesamiento y el control de temperatura durante el almacenamiento. Además, la alta calidad microbiológica de los ingredientes crudos, aditivos, así como la buena higiene del proceso de producción, son esenciales en la producción de productos sous vide microbiológicamente estables y seguros. Debido a la aplicación de una temperatura relativamente baja, si están presentes, los formadores de esporas no serán inactivados por el tratamiento. Por lo tanto, para reducir significativamente los formadores de esporas o las bacterias dañinas para la descomposición es necesario utilizar únicamente la materia prima de mejor calidad. Algunas bacterias, aunque no formadoras de esporas como *Listeria monocytogenes, Enterococcus faecalis* o *Staphylococcus aureus*, pueden plantear problemas de seguridad debido a su estructura de pared celular específica. La técnica sous vide puede combinarse con métodos no térmicos para controlar la microflora existente, especialmente microorganismos patógenos. Este resumen presenta los tipos de métodos, condiciones de cocción y características cualitativas de los alimentos sous vide típicos (hechos de carne, mariscos, verduras y otros materiales crudos). Se presentan las ventajas y desventajas de la cocción sous vide que tienen un impacto en la calidad nutricional y sensorial y la seguridad alimentaria.

Palabras claves: procesamiento mínimo, "obstáculos", sous vide, alimentos, seguridad alimentaria

Trattamento minimo degli alimenti: tecnica di cottura sous-vide

Riassunto

Gli alimenti ‘’Zero‘’(non trasformati) e quelli minimamente trasformati diventano sempre più popolari come conseguenza di un atteggiamento crescente dei consumatori riguardo alla loro origine. Tecniche di trattamento minimo si sono dimostrate molto efficaci nel prolungamento della durata di conservazione e nel miglioramento della qualità e della sicurezza di prodotti. Il metodo sous-vide è una tecnica di conservazione delicata e un esempio di “concetto di ostacolo”, che si concentra sul trattamento termico minimo degli alimenti. Le condizioni della cottura sous-vide sono molto diverse da quelle impiegate nei metodi di cottura tradizionali, o da quelle adottate dalla ristorazione e dall’industria alimentare. Come combinazione di sottovuoto e cottura precisa, da un lato, e di una dieta sana con nuove esperienze alimentari, dall’altro, il sous-vide guadagna rapidamente popolarità. Questa tecnica è applicata nel tutto il mondo, nella ristorazione, nel catering, nella produzione industriale e nelle famiglie. La sicurezza microbiologica dei prodotti cucinati sous-vide dipende dal controllo del tempo e della temperatura durante il processo di cottura, dal raffreddamento rapido dopo il trattamento e dal controllo della temperatura durante lo stoccaggio. Inoltre, un’elevata qualità microbiologica delle materie prime e una buona igiene del processo di produzione sono essenziali nella produzione di prodotti cucinati sous-vide microbiologicamente stabili e sicuri. A causa dell’applicazione della temperatura relativamente bassa, i batteri sporogeni, se presenti, non saranno inattivati dal trattamento. Pertanto, per ridurre significativamente la presenza di microorganismi nocivi è necessario utilizzare solo le materie prima di migliore qualità. Alcuni batteri, anche se non formano spore, come *Listeria monocytogenes, Enterococcus faecalis* o *Staphylococcus aureus,* possono rappresentare un problema di sicurezza dovuto alla specifica struttura della loro parete cellulare. La tecnica di cottura sous-vide si può combinare con successo con metodi non termici per il controllo della microflora esistente, in particolare, dei microorganismi patogeni. Nel presente riassunto sono presentati i tipi di metodi, le condizioni di cottura e le caratteristiche qualitative tipiche per gli alimenti e pasti cucinati sous-vide (a base di carne, frutti di mare, verdure e altre materie prime). Gli autori hanno presentato i vantaggi e svantaggi della cottura sottovuoto che influiscono, tra l’altro, sulla qualità nutrizionale e sensoriale e sulla sicurezza degli alimenti.

Parole chiave: : trattamento minimo, “ostacoli”, sous-vide, cibo, sicurezza alimentare