



Review

Effect of low temperatures on shrimp quality

M. Strateva*

Department of Veterinary Anatomy, Histology and Embryology, Faculty of Veterinary Medicine, Trakia University, 6015 Stara Zagora, Bulgaria

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Abstract. *Shrimp is one of the most preferred seafood for consumption. The high water content and nutrients place shrimp in the category of perishable fast spoiling foods. In order to avoid deterioration of their quality, it is necessary to freeze and store them at low temperatures. Fluctuations in temperature can cause thawing and refreezing with recrystallization. In frozen products, the amount and size of ice crystals play a major role in the quality of these products. Despite the wide application of freezing, various histological, physicochemical, microbiological, enzymes and pH changes occur with varying degrees of manifestation. The objective of the review was to discuss the effect of freezing on the quality of shrimp used for human consumption.*

Keywords: shrimp, freezing, frozen storage, histological changes, physicochemical changes, microbiological changes

Introduction

Shrimp is one of the most preferred seafood for consumption. It is extremely sought after and valued due to their high nutritional value (Liu et al., 2021). The quality and safety of food products are paramount to consumer health (Ortea et al., 2012). This is due to the fact that meat is a matrix of complex nature. It contains a colorful set of substances such as lipids, proteins, carbohydrates, water. All of them are involved in different and complex reactions, both from a physiological and biochemical aspect. These are the reactions that, during frozen storage, can lead to undesirable qualitative changes (Shi et al. 2018; Zhang et al.

2023). Freezing methods are able to affect the composition of meat products (Stella et al. 2022). An in-depth understanding of the changes taking place during the freezing and thawing processes is the basis for improving the quality of frozen and thawed meat products (Zhang et al., 2023). The changes that occur in meat are related to sensory, chemical, microbiological and physical factors. Taste, smell, appearance and texture are qualities perceived through the senses. The group of sensory changes includes, for example, changes in the color of meat (darkening or browning; Maillard reaction). Chemical analyses detecting changes in the chemical composition are necessary to reveal the degree of decomposition and, accordingly, the

*e-mail: mariyana.strateva@trakia-uni.bg

formation of harmful compounds affecting meat quality (Duarte et al., 2020). In frozen meat, it is assumed that the two main oxidative processes affecting its quality are the oxidation of proteins and fats (Liu et al., 2022). For this reason, consumer awareness of activities such as quality control and shelf life monitoring of food products is growing. In this direction, they become increasingly critical and uncompromising (Sun et al., 2023b). Trading in global shrimp markets is gaining more and more popularity. The EU introduced a number of regulations controlling the quality and safety of food products reaching the final consumer (Ortea et al., 2012; Chen et al., 2022; Zhao et al., 2022; Amalia et al., 2023). This is a step of paramount importance, as cases of unregulated and deliberate mislabeling of shrimp leading to fraud for financial benefit to perpetrators are also on the rise (Davis et al., 2022). The objective of the review was to discuss the effect of freezing on the quality of shrimp used for human consumption.

Freezing and frozen shrimp storage

High water content and nutrients place shrimp in the category of perishable food (Farajzadeh et al., 2016; Jin et al., 2018; Han and Gokoglu, 2022; Peng et al., 2022). This is due to cathepsin activity, high bacterial activity and protein destruction (Abd-El-Aziz and Moharram, 2016; Lan et al., 2020; Mehta et al., 2023), resulting in decrease in shrimp quality (Peng et al., 2022). In order to avoid deterioration of quality, it is necessary these processes to be restricted. This task can be accomplished by the use of freezing and frozen storage. Storage at low temperatures is a familiar method and a possible way to extend shelf life (Sriket et al., 2007; Tsironi et al., 2009; Zhang et al., 2020; Han and Gokoglu, 2022). Despite the positive effect, undesirable changes occur during frozen storage of shrimp. They are associated with color, occurrence of processes such as protein denaturation and lipid oxidation, ice crystal formation and recrystallization (Tsironi et al., 2009; Zhang et al., 2020; Liu et al., 2022; Pan et al., 2022; Qi et al., 2022; Sun et al., 2023b). The end result is rancidity and unpleasant taste. Weight loss and dehydration have been

observed, combined with changes in meat structure, reduced water binding capacity, autolytic and microbial spoilage (Bak et al., 1999; Lan et al., 2020; Chen et al., 2022). What has been presented so far shows that yet, the preservation of shrimp by freezing is not able to effectively guarantee their quality (Peng et al., 2022). Literature on the topic of freezing and subsequent frozen storage of shrimp offers a broad overview of various scientific advances in this field. Some of them have been carried out in laboratory conditions, others have a wider application. However, it seems that there is still a lack of a unified opinion indicating both the freezing method and the frozen storage time, which, apart from being able to preserve the quality of the shrimp, on the one hand, to be affordable for implementation in the various technological processes, on the other hand.

Influence of storage temperature in shrimp

Frozen shrimp can be of high quality as a food product if frozen immediately after capture (Tsironi et al., 2009). Zhang et al. (2020) pay attention to the temperature factor. Fluctuations in temperature can cause thawing and refreezing with recrystallization. The formed crystals then have larger sizes than the originally formed ones. Tsironi et al. (2009) and Jin et al. (2018) found frozen storage temperature to be an important element in efforts to preserve the quality of frozen shrimp. According to them, it is necessary to monitor the storage temperature. The aim is to promptly avoid fluctuations in its amplitudes. Temperature monitoring will prevent thawing and subsequent re-freezing leading to reduced final shrimp quality. Alsailawi et al. (2020) believe that temperature can also have a negative effect. According to them, when temperature is below freezing, certain chemical reactions are able to be accelerated and, therefore, proceed at a faster rate. Examples of similar type of reactions indicate denaturation and coupling of proteins with free fatty acids. According to Alsailawi et al. (2020), the formation of protein/free fatty acid complexes is more pronounced at -29°C than at temperatures slightly above 0°C . Protein denaturation, on the

other hand, increases at -12°C and -16°C , instead of at -5°C and -10°C . According to Zhang et al. (2020), different storage temperatures have different effect on shrimp muscles. According to them, more muscle damage would result from storage in the range of -24°C to -80°C than between -18°C and 4°C . Yu et al. (2018) informed that when shrimp were frozen at -35°C (air-blast freezing), a deterioration of their final quality could be expected after approximately 3 months of storage. Bak et al. (1999) believed that a shelf life of 12 months could be achieved at -18°C . According to Alsailawi et al. (2020), there was a potential to not affect frozen seafood quality if temperature fluctuations were small. Otherwise, with large fluctuations, quality is seriously affected.

In this regard, our opinion overlaps with that of Yu et al. (2018) that a more comprehensive and in-depth study of freezing and storage methods of shrimp is needed. This would lead to the development of a more effective and adequate method capable of positively influencing the extension of their shelf life. The perishable seafood trade should direct efforts and resources to discover ways to improve storage technologies. A leading goal in this direction is to achieve optimal quality of the final product, since the storage period is different for different types of seafood.

Freezing rate and formation of ice crystals in shrimp

The freezing rate factor is directly related to the formation of ice crystals (Su et al., 2014). In shrimp, the temperature limits for ice formation are set to be within the range of -2°C to -5°C (Yu et al., 2018). In frozen products, the amount and size of ice crystals play a major role in the quality of these products (Su et al., 2014). Yu et al. (2018) determined the fast-rate freezing methods to be responsible for the occurrence of ice crystals of small sizes, uniformly positioned. Small ice crystals are not able to cause significant structural damage and organoleptic changes (Su et al., 2014).

The formation of ice crystals is a process known as nucleation. There is a growing number of reports that are related to the proposal of new freezing

technologies focusing on control of nucleation. According to these data, to influence the formation and subsequent growth of ice crystals, it is necessary to accelerate the freezing rate. In this way, the rate of heat transfer is affected, which appears to be greater than the rate of water penetration. Thus, uniformly distributed large number and small volume of intracellular crystals are formed (Sun et al., 2023a). The number of ice nuclei formed in the early nucleation period, combined with their growth rate, are determining factors for the localization and size of the crystals (Su et al., 2014). Short-term freezing causes the occurrence of a large number of small ice crystals. They can be distributed both extracellularly and intracellularly. On the other hand, long-term storage causes the appearance of extracellular large ice crystals (Sun et al., 2023a). Su et al. (2014) added to the information on ice crystal size by stating that freezing at slow rates leads to the formation of large extracellular crystals.

Today, various methods of freezing shrimp have been developed and tested. Some of them are related to the use of liquid nitrogen as a cryopreservative. Others are related to air-blast freezing of shrimp. Still others use a simple refrigerator. The changes occurring are summarized by Yu et al. (2018). They found the presence of the smallest ice crystals in tissue structures after liquid nitrogen freezing of shrimp. Larger ones were observed with the air-blast freezing method and a temperature of -35°C . The largest and most irregular ice crystals were recorded after freezing at -18°C in an ordinary refrigerator with a freezer compartment. Wei et al. (2024) by applying magnetic field-assisted freezing, put forward the thesis that when water molecules were exposed to a magnetic field, thermal variations were registered. These, in turn, slowed down the formation of ice crystals by lowering the freezing point of the water molecules.

Frozen shrimp has been of interest to consumers for quite some time. It is preferred because of their extended shelf life and appropriate price (Tsironi et al., 2009). Frozen storage, suppressing microbial growth, maintains their good quality. Deterioration can be expected during distribution (transport), handling and processing, long periods of storage, repeated freeze-thaw cycles (Zhou et al., 2023). Freezing and subsequent thawing have a detrimental

effect on the muscles of aquatic organisms. Factors directly affecting muscle properties are related to storage temperature as well as freezing and thawing rates (Díaz-Tenorio et al., 2007). In order to preserve high quality of shrimp, it is clear that low temperature preservation is widely used (Yu et al., 2023). Thanks to freezing, it is possible to maintain high quality of shrimp by inhibiting microorganisms, biochemical and physiological processes (Sun et al., 2023a). Despite the benefits of applying freezing, it is possible to end up with a poor quality product. When freezing is applied at a slow rate, ice crystals of irregular shape and large sizes are formed. They are the cause of tissue damage, which is directly related to loss of nutritional value of the product. This result would necessarily affect the consumption and subsequent processing of shrimp (Liu et al., 2022). When freezing, the water that is outside the cells freezes first. This is how extracellular crystals are formed. Migration of intracellular water then occurs due to osmotic pressure. Water molecules from it join the already formed ice masses and form large ice crystals. These, in turn, exert mechanical pressure on the muscle fibers, damaging them (Sun et al., 2023b).

Changes occurring in the physico-chemical profile of frozen shrimp

Enzymes

During frozen storage, the action of various endogenous enzymes occurs. Softening of muscles under conditions of frozen storage is a consequence of enzymatic reactions (Zhou et al., 2023). Shrimp muscles are affected by cathepsins, calpains and trypsin. It is able to break down collagen. The initial softening of muscle tissue is thought to occur under the action of trypsin. This process could be prevented after decapitation of shrimp before storage. This is because the localization of the hepatopancreas in shrimps is in their head. Regarding the action of other endogenous enzymes resulting in changes, calpains have been studied. They also relate to textural changes. These result from the destruction of lysosomal structures. They have a detrimental effect on myofibrillar proteins.

Violating their integrity, they release various peptides resulting in muscle softening. The heavy chain of the myosin molecule breaks down under the proteolytic activity of cathepsin (Xiao et al., 2023; Zhou et al., 2023). High cathepsin activity leads to rapid spoilage of shrimp (Lan et al., 2020). The high concentration of solutes in the unfrozen water fractions can result in increased enzyme activity with marked changes in taste and texture (Zeng et al., 2005). During autolysis during storage, collagenases and proteinases are released from the shrimp hepatopancreas, in addition to trypsin. Their action is related to the breakdown of collagen. Serine collagenase has a detrimental effect on muscles by softening them (Sriket et al., 2011). According to Sriket et al. (2010), freshwater shrimp are more susceptible to tissue softening compared to saltwater shrimp. Freezing and thawing processes have been shown to damage muscle fibers. In this way, the integrity of cell organelles is also damaged. As a result, mitochondrial and lysosomal enzymes are registered in the sarcoplasm. These enzymes are involved in protein fragmentation (Sriket et al., 2007; Lan et al., 2020). During frozen storage, compounds such as lyso-phospholipids and free fatty acids are produced. They result from enzymatic hydrolysis of phospholipids and triglycerides. The enzymes catalyzing this reaction are phosphorylase A2 and lipase (Stella et al., 2022). The appearance of various enzymes such as nuclease, lipase, protease after the destruction of muscle fibers causes an increase in malondialdehyde and accelerates the oxidation reaction (Li et al., 2020). The loss of redox balance during lipid oxidation occurs due to the release of antioxidant substances. During frozen storage, antioxidant enzymes have reduced activity and oxidizing substances accumulate (Jiang et al., 2021).

Proteins

Protein is a major component in aquatic foods (Qi et al., 2022). Shrimp is a source of high-quality protein (Zhao et al., 2022). Proteins in the composition of shellfish are presented as stromal, myofibrillar and sarcoplasmic. For shrimp, proteins are unstable structures. They

are rapidly degraded or denatured under adverse conditions (Kamal et al., 2000). Protein oxidation according to Zhou et al. (2023) occurs in shrimp during freezing and subsequent frozen storage. The reason for its manifestation is determined by the destructured muscles. Protein oxidation as a process is related to covalent modification of proteins. It results from the release of reactive free radicals. Indirectly, protein oxidation occurs due to free radical chain reaction byproducts such as reactive nitrogen species and reactive oxygen species (Qi et al., 2022). Protein decreases due to loss of droplets containing dissolved sarcoplasmic protein. At low temperatures and long-term storage of shrimp, according to Pan et al. (2022) oxidation of myofibrillar proteins occurs. Shi et al. (2017) linked protein oxidation to a decrease in SH-content, leading to the formation of disulfide bonds. In the *Solenocera melantho* shrimp, Shi et al. (2017) found that SH content was lower during frozen storage at -20°C, compared to -30°C and -40°C. This means that lower temperatures are likely to have a beneficial effect by preventing protein oxidation from occurring in shrimp. For Qi et al. (2022), the occurrence of protein oxidation is a factor leading to a change in quality. This change is due to protein aggregation and cross-linking, resulting in color change. After these processes, disulphide and carbonyl bonds are formed. In this way, a loss of protein functionality is achieved. According to Zhang et al. (2020), the causes of protein denaturation are related to ice crystals and their growth. Hydration layers around proteins are disrupted. Lan et al. (2020) believe that frozen storage is capable of causing oxidative denaturation of proteins. Conformational changes in proteins are present after the formation of carbonyl groups. Carbonyl content is related to protein oxidation. Denaturation of proteins occurs after freezing and thawing, which destroys their tertiary and secondary structures (Shi et al., 2017; Sun et al., 2023b). During long-term storage of shrimp, protein degradation is different, but sarcoplasmic proteins remain unchanged. Myofibrillar protein decreases, an increase is reflected in the alkaline soluble type. The role of proteins in the deterioration of shrimp quality is not insignificant (Pan et al., 2022). According to Qi

et al. (2022), protein oxidation leads to decreased shrimp quality related to their chewing, elasticity and firmness. Regarding biochemical processes after freezing, protein denaturation is important for muscle structure (Díaz-Tenorio et al., 2007).

Fats

Lipids, and especially phospholipids, are of great importance in crustaceans (Miniadis-Meimaroglou et al., 2008). The increase or decrease in the amount of fat may be due to individual characteristics. It has been shown that variation can be observed even within the same shrimp species (Kamal et al., 2000). Deep freezing processes according to Jin et al. (2018) can reduce lipid oxidation in shrimp. For Qi et al. (2022), the occurrence of lipid oxidation is a factor affecting quality. It worsens due to the occurrence of discoloration of water products, as well as due to the production of unpleasant aromas, tastes and toxic substances. The occurrence of endogenous enzymes during freezing, according to Shi et al. (2017), causes lipid oxidation to occur. Enzyme reactions are directly related to the duration of storage and the temperature at which they occur. The manifestation of fat oxidation also depends on these two important factors. According to Qi et al. (2022), the occurrence of lipid peroxidation during storage of aquatic products is an inevitable phenomenon. It is the reason why alkyl peroxy, hydroperoxides and alkyl radicals are found in these products. According to Pan et al. (2022), the deterioration of shrimp quality during storage is due to protein changes. On the other hand, according to Qi et al. (2022) lipid oxidation and not so much protein oxidation is of greater degree of significance for food qualities such as taste and appearance.

Lipid oxidation as a mechanism involves three main stages. These are initiation followed by propagation and finally termination. With the help of various catalysts such as metal ions, heat, free lipid radicals are initially formed. These radicals bind to oxygen and lead to the formation of peroxy radicals. Peroxy radicals, in turn, interact with other lipid molecules, and as a result of these reactions, hydroperoxides and free radicals are obtained.

In the last stage, referred to as termination, non-radical products are obtained from the interaction of free radicals. Oxidation of lipids can happen in two ways - enzymatic and non-enzymatic. During the enzymatic way, free fatty acids are broken down into triglycerides. This is how rancidity and the unpleasant aroma are produced (Prabhakarn et al., 2020).

The amount of lipids during frozen storage at low temperatures usually decreases. Hydrolysis of phospholipids and triglycerides occurs. This process takes place under the control of enzymes such as phosphorylase A2 and lipase. As a result, free fatty acids are produced. Free fatty acids cause a change in taste, leading to bitterness and metallic taste. They are also the cause of lower nutritional values of the products (Stella et al., 2022).

During frozen storage, meat components interact due to the catalysts and lipids present. In this way, they become vulnerable to oxidation processes. Iron and myoglobin are some of these catalysts. Lipid oxidation is considered to be a major cause of muscle breakdown during frozen storage. The course of oxidation reactions is a critical point affecting texture, color, nutritional value and taste. Lipid oxidation occurs due to the presence of malondialdehyde and cholesterol oxidation products (Al-Dalali et al., 2022). The period of frozen storage affects the course of the process related to lipid oxidation (Al-Dalali et al., 2022). According to Liu et al. (2022), TBARS values increase during frozen storage. This means that they have a role in the course of lipid oxidation. A reason for the increased TBARS values is found in the recrystallization process. Recrystallization, in turn, is the cause of breaking the integrity of cell membranes and the respective release of pro-oxidant substances. Wereńska et al. (2022) also published information showing an increase in the proportion of TBARS. According to the authors, the reason for the increase in values is found as a result of chemical reactions between proteins and malondialdehyde. They occur as a result of the formation of secondary oxidation lipid products. Wereńska et al. (2022) added that protein-lipid complexes are produced as a result of the reaction between proteins and malondialdehyde. These complexes participate in reducing the nutritional

value of meat by taking part in the breakdown of amino acids.

During frozen storage, lipid oxidation is a common phenomenon. Frozen storage has a strong influence on the appearance of secondary oxidation lipid products. TBARS is the indicator that is monitored and evaluated for whether secondary products are formed. During different temperature regimes, the amount of TBARS varies. The data show that at -8°C the values are higher. Lower values have been recorded at temperatures of -18°C and -25°C. This shows that the temperature factor is important for lipid oxidation. In this regard, it becomes clear that higher temperature exacerbates the course of lipid oxidation (Li et al., 2020).

Lipid oxidation is a process that is difficult to control and inhibit. This is because in this process peroxides are formed, that are able to react with other components as well. Peroxides are accepted as primary oxidation products, although they are chemically unstable structures. Along with the primary ones, secondary oxidation products such as aldehydes, ketones and reactive hydroperoxides are also formed. Secondary oxidation products are responsible for the rancid unpleasant smell and taste of the meat. They also lead to a change in color. It is aggravated by the increased proportion of metmyoglobin and formation of malondialdehyde (Bian et al., 2022; Wereńska et al., 2022). According to Liu et al. (2022), the increased concentration of substances obtained as a result of lipid oxidation in a liquid that is located around proteins promotes the oxidation of them as well.

Water content

In foods of meat origin, water is a major component. Its role is particularly important in aquatic organisms. In this regard, the quality of aquatic foods will depend significantly on the physical condition of water (Lan et al., 2020). The formation of ice masses will lead to a decrease in water content. This in turn will lead to muscle damage and protein oxidation (Sun et al., 2023b). The thawing and freezing processes lead to water loss. Water can be lost as droplets after thawing (Lan et al., 2020). Droplet loss is associated with

disrupted fiber structure, which also affects their ability to hold water (Sriket et al., 2007). According to Liu et al. (2024), reduced water holding capacity is caused by protein denaturation and severe damage to cell structures. When the fiber's ability to bind water is high, it means that there is a strong bond between water and protein molecules.

pH

When performing shrimp quality control, pH measurement is essential (Han and Gokoglu, 2022). This is an indicator that shows the occurrence of changes in the physicochemical profile in shrimp (Solval et al., 2014). Changes in pH values are recorded after the death of the shrimp. The earliest this can be reflected is an hour after death. The initial pH (6.95) one hour after death was determined to be pH 6.33. A change in this indicator when measured on day 7 of storage on ice was recorded as pH 8.18 in decapitated shrimps (Kamal et al., 2000). Han and Gokoglu (2022) and Liu et al. (2024) supported the idea that at the beginning of storage the pH decreased but then increased. Due to the manifestation of hydrolysis, pH decreased in the first hours after death. The reason is the metabolization of available glycogen to lactic acid. pH decreases as rigor-mortis occurs. On the other hand, an increase in pH can occur after rigor-mortis terminates due to bacterial action (Kamal et al., 2000) and biochemical reactions (Solval et al., 2014). Han and Gokoglu (2022) supported this view. Kamal et al. (2000) reckoned that at pH above 7.5 shrimp spoilage occurred. Liu et al. (2024) found an unacceptable pH value >7.3 in *Penaeus vannamei*. Jin et al. (2018) contrary to Kamal et al. (2000) and Liu et al. (2024) found a pH of 7.7 as a value for good shrimp freshness. Han and Gokoglu (2022) also indicated that pH values of 7.7 or less are characteristic of first-quality shrimp. Jin et al. (2018) subjected shrimp to freezing at different temperatures such as -11°C , -18°C , -26°C and -37°C . Values were measured after 120 days of stay as follows: at -11°C pH-7.42; at -18°C pH-7.39; at -26°C pH-7.16; at -37°C pH-7.08. Han and Gokoglu (2022) supplemented the information with data and pH from 7.7 to 7.95 indicated acceptable

but not good shrimp quality. The quality of shrimp with pH above 7.95 was defined as unacceptable quality. Solval et al. (2014), similar to Han and Gokoglu (2022), considered a pH of 7.7 to 7.95 to be associated with poor shrimp quality but still acceptable. Values above 7.95 for pH indicate shrimp spoilage has occurred. Jin et al. (2018) believe that freezing affects pH values by slowing down its rate of change.

In connection with the inconsistency in the categorization of the pH-values responsible for the freshness of shrimp, it is necessary to carry out a larger number of studies that show more results on the issue, so that there is no misleading information and wrong determination of this indicator in future works.

Microbiological changes

Changes occurring in shrimp after their death occur at a faster rate than fish. Their delicate taste is due to non-nitrogen substances and amino acids. But these components can easily be converted into nutrients supporting bacterial growth (Zeng et al., 2005). According to Abd-El-Aziz and Moharram (2016), the microorganisms found in shrimp reflect the microbial population in their habitat. Differences in the microbial load can be expected after different treatments starting immediately after the catch until transportation to the final destination. In general, there should be no difference in the quality of frozen shrimp. According to the authors, the microbial population should be kept approximately equal in the initial and final microbial counts of stored frozen shrimp. Abd-El-Aziz and Moharram (2016) shared the thesis that quality changes in shrimp have different from the microbial factor causing agents for its deterioration. They indicated unhygienic handling, transportation and fluctuations in the temperature range of storage.

Histological changes

The histological evaluation of fresh shrimp muscles according to Sun et al. (2023b) showed

a structure with intact and well-connected fibres. According to Zhou et al. (2023), shrimp frozen at -18°C for periods of 60 and 120 days showed changes in muscle tissue. Large extracellular spaces were observed between muscle fibres. The authors found a difference when performing a histological evaluation of muscles from shrimp with and without heads. Their conclusions suggested that muscle fibres are damaged to a greater extent in whole shrimp. They found a connection in these differences in the action of endogenous enzymes.

In histological analysis of fresh freshwater shrimp muscles, Sriket et al. (2010) found the pericellular tissue perimysium and endomysium to be well expressed. Mizuta et al. (1997) identified shrimp as a highly perishable food that required immediate refrigeration and post-harvest processing. When studying histological features of the connective tissue in the muscles of shrimp (*Penaeus japonicas*), they determined the presence of endomysium, perimysium and epimysium. In relation to the positioning of endomysium, they indicated its localization around each muscle fiber. Perimysium is a connective tissue surrounding the bundles of muscle fibers. As for epimysium, it is found as a connective tissue of greater thickness covering the muscles on their outer side. Microstructural changes according to Zhang et al. (2020) occur in shrimp after freezing. They registered increased intercellular spaces between the bundles of muscle fibers, destructive changes in the muscle fibers themselves, resulting in some to their complete destruction.

Conclusion

The condition of frozen shrimp should continue to be investigated, since the available information does not provide clear enough information on how exactly the freezing process and subsequent storage should be controlled and selected, so as to be able to guarantee a quality frozen end product. Closer cooperation between producers and scientists is needed to find concrete solutions related to shrimp freezing.

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