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The Effect of Water Activity on Preservation Quality of Fish, a Review Article

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Abstract: The water activity of foodstuffs is a very important aspect of food preservation. The growth of the various microorganisms stops at a given level of water activity and a comprehensive knowledge of these levels is essential for food processors as well as for research purposes. This study showed the relationship between spoilage of stored fish and water activity. The water activity (aw) played an important factor in fish spoilage and the growth of different microorganisms depends on its rate. If the aw reduced to 0.6, the growth of bacteria and moulds can be prevented. The detection of spoilage can be determined by controlling water activity and in the same time can be retarded by reducing the a_w of the fish by either drying or freezing to keep the fish in good stage with high nutritional and organoleptic quality. The linear approximation was analyzed with reference to the a_w, values of pure NaCl solutions and to a thermodynamic approach for a, prediction; it was found consistent and appropriate for a_w, estimation in moist salted fish products, with errors within the accepted range for intermediate moisture foods (IMF). This study is very important and can assist in preventing spoilage of fishes and their products particularly when production and processing operations are applied.

Key words: Fish spoilage · Water activity · Preservation

INTRODUCTION

A major application of water activity concerns the control of the microbial growth. Other aspects such as quality or organoleptic properties are important, but safety in food is the first and most significant criterion and this means the control of microbial growth. The lowest limit for growth in foods or any other item is around aw 0.6. I n the narrow range between aw 1 and aw 0.6 a large number of microorganisms can grow which are potentially dangerous to food. As a result, the regulatory agencies in many countries are now beginning to define water activity standards for processed foods. The most important microorganism in this context is *Clostridium botulinium* which stops growing at aw < 0.95. All other microorganisms have defined growth limits. Yeasts and molds tend to be more resistant to water activity than bacteria. Most pathogenic bacteria in food can be stopped by water activity of around aw 0.90, but to stop yeasts and molds it is necessary to lower activity to as little as aw 0.7 to 0.75. *Staphylococcus aureus, Clostridium perfringens, Bacillus cereus and Clostridium botulinium* are all very dangerous pathogenic bacteria in food. With the exception of *Staphylococcus aureus*, most pathogenic bacteria in food can be inhibited by water activity levels of less than aw 0.92 to 0.80. *Staphylococcus aureus* is inhibited at around aw 0.85.

Food spoilage means the original nutritional value, texture and flavour of the food are damaged, the food becomes harmful to people and unsuitable to eat [1]. It is a metabolic process that causes foods to be undesirable or unacceptable for human consumption due to changes in sensory characteristics [2-3]. As soon as a fish dies, spoilage begins. Bacteria will enter at a number of points, through the gills and into the blood vessels, through the lining of the belly cavity and eventually through the skin. In the flesh they can grow and multiply rapidly, producing disagreeable odours and flavours. Spoilage of fresh fish is a rather complex process and is caused by a number of inter-related systems, some of which are suppressed by others. The factors which principally contribute to the spoilage are the degradation of protein with a subsequent formation of various products like hypoxanthine and trimethylamine, development of oxidative rancidity and the action of microorganisms [4].

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Water activity is used in many cases as a Critical Control Point for Hazard Analysis and Critical Control Points (HACCP) programs. For many years researchers tried to equate bacterial growth potential with moisture content, they found that the values were not universal but specific to each food product. Earlier Scott [5] established that it was the water activity, not water content that correlated with bacterial growth. It was firmly established that growth of bacteria is inhibited at specific water activity values. FDA regulations for intermediate moisture foods are based on these values [6]. It is widely used in food science as a simple, straight forward measure of the dryness of food and foods typically have an optimum water activity at which they have the longest shelf life [7]. In general, water activity is the right measurement when microbial processes, including food spoilage, are of concern [8]. Recently, many researches have been acknowledged with the objective of evaluating the spoilage of seafood in general and fish in particular [9-13].

Accordingly, the objective of this study was to give clearer idea about the spoilage of fish in terms of its water activity as a main factor influencing spoilage process. In the light of above, this paper has been justified and the coming subtitles are essential to be explained. Moist salted fish is one of the oldest intermediate moisture foods (IMF) developed by man and moist salted-fish products are available in the markets of the world. In European countries this type of product is produced using herring *(Clupea harengus)*, anchovy *(Engraulis encrasicholus)* and sprat *(Clupea sprattus)*; in South America, anchovy *(Engruulis unchoita)* is used in Argentina and Uruguay and sardine *(Surdinella auritu)* in Brazil and other countries. Moist salted-fish products are also produced in Africa and Asian countries[10].

As is known, salt produces various effects which contribute to the preservation of food 11]. The most important of them and one that is easily quantified and related to spoilage is the decrease in water activity Taking into account that *a,* in moist salted-fish products remains between 1 and around 0.75 and because of the known difficulties in measuring *a,* in its higher range (just below 1 down to 0.95-0.80) 12] it is not surprising that there have been comparatively few experimental data published on such products. For this reason it was thought to be of interest to analyze the a, values that appear in the literature on moist salted-fish products and to relate them to the NaCl concentration [13].

The Relationship Between Water Activity and Moisture Content: Water activity in foods belongs to food science professionals for use in product development, quality control and food safety. It also became an important criterion for the evaluation and control of food safety and quality. Usefulness of water activity as a tool in quality and safety measurements was first suggested during 1950s when it became obvious that water content could not adequately account for microbial growth limitations. Since water activity describes the continuum of energy states of the water in the system, it is improper to divide water into categories defined as free bound or available water, as concluded in 2000 by panel of experts on water activity [14]. Like pH, every microorganism has a minimum, optimum and maximum water activity for growth. Yeasts and molds can grow at a low water activity. However, 0.85 is considered the safe cutoff level for pathogen growth. Examples of moist foods (those with water activities above 0.85) include most fresh fish, fruits and vegetables, actually having a relatively high water activity. It is only safe because of the multiple barriers of pH, water activity and mold growth, which is favored over pathogen growth [15].

Effect of Water Activity on Fish Spoilage: Food designers use water activity to formulate products that are shelf stable. If a product is kept below a certain water activity, then mold growth is inhibited. This results in a longer shelf-life. Water activity values can also help limit moisture migration within a food product made with different ingredients. If raisins of a higher water activity are packaged with bran flakes of a lower water activity, the water from the raisins will migrate to the bran flakes over time, resulting in hard raisins and soggy bran flakes. Food formulators use water activity to predict how much moisture migration will affect their product. In addition, water activity helps limit or slow certain undesirable reactions, such as non-enzymatic browning, fat oxidation, vitamin degradation, enzymatic reactions, protein denaturation, starch gelatinization and starch retrogradation. This too maintains product quality and extends shelf life [16]. Water activity is measure of the water available in a food that microorganism can use for growth. Pure water, with no dissolved substances, is 100% available for use by microorganisms. However, as certain materials, including salt and sugar, are dissolved in water, water activity is reduced and the water becomes less available for use by microorganisms, i.e. it is “tied up.” The water activity scale is 0.00 to 1.00, where 1 is pure water and completely available for microorganisms [17].

Bacteria on temperate water fish are all classified according to their growth temperature range as either psychrotrophs or psychrophiles. Psychrotrophs (cold-tolerant) are bacteria capable of growth at 0°C but with optimum around 25°C. Psychrophiles (cold-loving) are bacteria with maximum growth temperature around 20°C and optimum temperature at 15°C. Spoilage flora describes merely the bacteria present on the fish when it spoils and spoilage bacteria is the specific group that produce the off-odours and off-flavours associated with spoilage [18]. A bacterium on a piece of seafood will duplicate itself by dividing, in less than 20 minutes under ideal growth conditions (food, water and proper temperature). Those two bacteria will divide in the next 20 minutes, resulting in four bacteria[19]. The rate of microbial spoilage depends upon the number of micro-organisms present on the fish and the temperature at which the fish is kept. Rate of spoilage varies from fish to fish and can be listed as follows such as fatty fish spoil faster than lean fish, small-sized fish spoil faster than large fish of the same species, cold water fish spoil faster than warm water fish, round fish spoil faster than flat fish [20]. Rigor mortis is the progressive stiffening of muscle shortly after death. Rigor starts from the tail towards the head until the whole body becomes hard and stiff (inflexible). The fish remains rigid for a period ranging from one hour to three days. Bacterial spoilage does not start until the passage of rigor mortis. Earlier Spencer and Baines [21] reported that duration of rigor mortis depends more on the species of fish, size and catching method, handling of fish, temperature and physical condition of the fish. A delay in rigor water activity can be used to predict the direction of water movement - water will show net diffusion from regions of high water activity to regions of low water activity. For example, if honey (aw ≈ 0.6) is exposed to humid air (aw ≈ 0.7) the honey will absorb water from the air. Other examples of this dynamic property of water activity are moisture migration in multidomain foods (e.g. cracker-cheese sandwich), the movement of water from soil to the leaves of plants and cell turgor pressure. Since microbial cells consist of high concentrations of solute surrounded by semipermeable membranes, the osmotic effect on the free energy of the water is important for determining microbial water relations and therefore their growth rates. Higher aw substances tend to support more microorganisms. For instance, bacteria usually require at least 0.91 and fungi at least 0.7 to grow [22]. Microorganisms have different minimum levels of water activity for growth. Bacteria are generally the most sensitive and nearly all are inhibited at a water activity of less than 0.90-0.91. Molds and yeasts are more tolerant of high levels of solutes in water and therefore lower water activity. Their minima for growth are 0.70- 0.80 and 0.87-0.94, respectively. A water activity of 0.60 or lower will prevent growth of all microorganisms [23].

In practice experimental values of a_w, measured on salted fish products can deviate significantly from predicted ones, independently of the model that has been utilized. In such a situation the straight line approximation may be useful for a quick assessment if new measurements are necessary. However, approximation results in greater differences, especially at high concentrations, this being the region of practical importance. It is obvious that the absolute differences with the estimation will always be within the range of experimental errors commonly accepted for the determination of a_w, because they will only affect the second decimal by a unit or less. The apparently contradictory result that a larger error is obtained when using approximation [24] than with the linear approximation can be easily explained if the fact that a slight increase in (J with molality will tend to straighten expression [25] over a range wider than the one corresponding to the simple linearization is taken into account.

There is no totally satisfactory explanation to justify the experimental points in which the molality is larger than that corresponding to saturation and a_w, is less than what could be expected for saturation. Most of these points correspond to moist salted anchovy heavily pressed; thus, on a same quantity of muscle base, the brine is less than that corresponding to fish either lightly pressed or not pressed at all. Under these conditions it may be accepted that the medium exerts some influence on the a_w, values; and disregarding the possibility that solid NaCl has been included in the samples that were analyzed that would equally have influence on the amount of salt in 'solution' in the muscle. Pressing would have in practice a drying effect on fish. Experiments carried out in our laboratory to answer industry's demands to find the causes of spoilage in salted anchovy and salted and cold-smoked patagonian haddock have always resulted in a substantial decrease in the content of NaCl with reference to the normal values for saturation and, therefore, an increase in the water activity. The low values for NaCl content can be the result of several factors: not enough salting (insufficient amount of salt or too short salting time); excesive washing of salted fillets (to eliminate crystals of solid salt); skinning of the fillets in hot brine, etc. There will exist the possibility for a quick estimate of the a_w, value by determining either water content or NaCl. As determined for cod and extended for other species, there is a linear relationship between the water and NaCl contents in moist salted fish. Using this information together with expression [26], aw, can be estimated.

In conclusion, the microbial and chemical stability of fish and fish products depends on the (aw) of the product. Most bacteria cannot grow below aw 0.9, but *Staphylococcus aureus* can grow down to approximately aw 0.85. In freshly caught fish, aw is above 0.95 and can be decreased by drying and salting processes to reduce the rate of microbial growth as well as the range of microorganisms that can grow. The microbial and chemical stability of fish products during processing and storage is highly dependent on their a_w contents. The fish with an a_w less than 0.6 are microbiologically stable. An expression to estimate a_w, in moist salted fish is presented. This expression can be adequately related to published data on moist salted fish products and to a current thermodynamic approach to estimate water activities in aqueous solutions. In practice this relationship may be useful to estimate a_w, in moist salted fish when specific equipment is not available or to check individual measurements *of* a_w.

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