Squid: Gastrophysics of Squid – from Gastronomy to Science and Back Again

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The history of physics has demonstrated repeated ventures into other disciplines turning them into physics, e.g., astronomy, geology, chemistry, and biology, and this is possibly about to happen with gastronomy, turning some gastronomy into gastrophysics. We will demonstrate how this works by using squid as an example.

Introduction

Gastrophysics is an interdisciplinary field of science that can be defined as qualitative reflections and quantitative studies of all gastronomic aspects pertaining to food, including culinary precision and transformations, preparation techniques, texture, and organoleptic properties, with a focus on physical effects and physico-chemical characterization (Mouritsen 2012; 2016; Mouritsen and Risbo, 2015). The empirical basis of gastrophysics is gastronomy itself, as well as food and food preparations of specific gastronomical value and potential. It is possible that gastrophysics in combination with neurogastronomy (Shepherd, 2012) can furnish the scientific underpinnings of gastronomy at large. This definition of gastrophysics is different from the one recently adopted by Spence (2017), who put less emphasis on the physical sciences and more on psychology.

The starting point for a gastrophysical study is a gastronomically inspired question. In the context of cephalopod gastronomy (Mouritsen and Styrbæk, 2018; 2020), which deals with the culinary aspects of squid, cuttlefish, and octopus, key gastronomical questions pertain to texture and flavour. A relevant question could be: how does one treat the muscular tissues of cephalopods, specifically the mantle and arms, and for squid also the tentacles and retractor muscles, to obtain a particular structure that leads to a desired texture and mouthfeel? Although many cookbooks contain recipes for dishes with cephalopods, and there are a couple of older cookbooks dedicated to octopus and squid (Cronin, 1981; Schultz and Regardz, 1987), there is very little published about the culinary sciences of cephalopods. We shall here demonstrate how we have carried out a gastrophysical investigation of the texture and flavour of Danish squid, leading to new scientific insights, new culinary precisions, and new products of gastronomical value (Faxholm et al., 2018; Schmidt et al. 2020, 2021).

The Challenge of Tough Muscular Fibres

Cephalopods such as squid contain about four times as much collagen as finfish, and the collagen is much more cross-bound and hence much stronger in cephalopods. Cross-binding is a determining factor for the toughness of the tissues. In addition, the muscle fibres in cephalopods are longer and typically ten times thinner than in finfish, rendering the muscular structure of cephalopods smoother than in finfish. These facts, together with the three-dimensional organization of the cephalopod muscles, are the main reasons why these organisms can use the principle of a muscular hydrostat to exhibit an artistic degree of mobility in all directions. The structure of these fibres controls the texture and mouthfeel of cephalopods and is hence of utmost importance for how texture makes taste (Mouritsen and Styrbæk, 2017). The challenge in the culinary techniques applied to squid is how to avoid toughness and provide a desirable mouthfeel.

The organization of the muscular fibres in different cephalopods and in different parts of the cephalopods, i.e., arms, tentacles, and mantle, are different (Mizuta et al., 2003; Kier and Stella, 2007; Kier, 2016). These differences are crucial for the use of cephalopod meat as food and how tender it will be. For example, squid, because of their special ability to perform jet-repulsion swimming, have particularly strong muscles circularly organized around the mantle. This implies for fried squid dishes that cutting the conventional rings across the mantle is, in fact, the worst possible way of achieving mechanical tenderization. Cutting along the long direction of the mantle severs more muscle fibres and leads to a more tender product with a more appealing mouthfeel (Melendo et al., 1997). Some insight into the physical structure of the muscles in cephalopods is therefore a useful guide for the field of gastronomy.
Texture of Squid

There are many different ways of preparing squid, from raw, raw-marinated (ceviche), cooked, steamed, grilled, smoked, and fried to fermented in its own intestinal enzymes (Mouritsen and Styrbæk, 2018). We have investigated the application of *sous vide* techniques for tenderizing squid mantle (Faxholm *et al*., 2018; Schmidt *et al*., 2021) and studied the resulting texture by texture analysis and the collagen structure by second-harmonic-generation microscopy.

Texture analysis is a mechanical technique that involves applying force, e.g., by compression or shearing, to the material using different probes (cylinder, knife-blade, etc.). The result is a graph showing the relationship between the applied force of the probe and the deformation of the tested material over time for a given loading rate. Proper interpretation of the data can yield information about textural parameters like hardness, springiness, toughness, stickiness, and crispiness. Figure 80.1 shows an example of such a measurement of mantle from squid (*Loligo forbesii*) before and after *sous vide* treatment. From the figure, we can determine the maximum force needed to shear the squid meat (maximum shear force) as well as calculate the area below the force versus time curve (toughness) in a defined interval. The maximum shear force and toughness reveal information about the muscle tenderness, since they are inversely correlated.

Texture analysis profiles may be compared with results from microscopy, as the applied force of the probe depends on the structure and state of the collagen network inside the meat. The highly ordered molecular structure of collagen fibrils and the lack of optical symmetry give collagen the ability to interact with light in a non-linear fashion and behave as a so-called second-harmonic-generation material. When illuminated with strong laser light, such a material can ‘combine’ two incoming photons into one and generate light with exactly half the wavelength of the incoming light. This can be used to image the structure of squid muscles and determine how the microscopic organization of collagen changes during preparation. The technique allows non-invasive imaging of the structure of squid muscles, thereby revealing how the microscopic organization of collagen changes during preparation. Furthermore, since it uses far-red laser light, it can penetrate deep inside tissue (Brüggemann *et al*., 2010).

Examples of micrographs of squid mantle before and after *sous vide* treatment are shown in Figure 80.1. In the raw tissue (Figure 80.1a), the collagen organizes in a dense network of long linear bundles that entangle in the lateral direction in a roughly perpendicular manner. After *sous vide* treatment (Figure 80.1b), the signal intensity decreases, indicating that the heat treatment has changed the molecular structure of the collagen as the squid becomes more tender. A few intact collagen fibres are seen, surrounded by what appears to be partly or fully denatured collagen.

Texture analysis and microscopy do not reveal any information about what textural profile and mouthfeel may be perceived by humans. Hence, we performed a sensory evaluation using a so-called quick method developed and modified for the present purpose with a focus on attributes of taste, texture, and mouthfeel. The results of this test revealed that, even if the longest cooking time resulted in a more tender texture profile, this preparation was not the most liked. Rather, our evaluation demonstrated that a relatively short cooking time (but not raw) was preferred, as it yielded a better taste and a more stimulating texture during mastication, whereas longer cooking times yielded an overcooked surface, a bitter taste, and a dull mouthfeel throughout mastication.

FIGURE 80.1 Force versus time at loading rate 2 mm/s for a squid mantle sample before and after *sous vide* treatment (55 °C for 0.5, 1.0, and 1.5 h). Insets show second-harmonic microscopy images of the collagen structure when raw (a) and after *sous vide* treatment (b). The scale bars correspond to 50 µm.
Umami Taste of Squid

One of the most characteristic features of the flavour profile of seafood is umami, the fifth basic taste (Mouritsen and Styrbæk, 2014). This is true of fish, shellfish, and cephalopods, as well as seaweeds. Umami is elicited by free glutamate interacting with the glutamate receptor, often in a synergistic manner with free nucleotides such as inosinate, adenylate, and guanylate (Zhang et al., 2008; Mouritsen and Khandelia, 2012). There is, however, very little information available about the contents of these compounds in squid. Japanese squid has been found to contain high levels of adenylate, up to 184 mg/100 g (Yamaguchi and Ninomiya, 2000).

We have measured the levels of free glutamate in Danish squid by chemical analysis (Faxholm et al., 2018; Schmidt et al., 2021) and found that squid mantle contains 63 mg/100 g (wet weight) (Figure 80.2). This value is somewhat higher than the content reported from Japanese squid (UIC, 2018) of 20–30 mg/100 g, a value that presumably is based on whole Japanese flying squid (Todarodes pacificus) and not only mantle. We have also measured the total amount of glutamic acid in Danish squid and found that the relative potential for forming free glutamate is much larger than indicated by the content of free glutamate. This potential may be released by culinary processes, in particular hydrolysis and fermentation. Further investigations are needed to indicate which preparation techniques will yield the most desirable amino acid profile outcome possible.

The data in Figure 80.2 for raw squid mantle shows that it contains sweet-tasting free amino acids (Ala, Gly, Thr, and Ser) and a relatively high content of umami-potent free amino acids (Glu and Asp). This suggests that the sweet taste known from fresh raw squid is caused to some extent by the presence of sweet free amino acids. Furthermore, squid may have a great potential for umami taste when prepared, through hydrolysis and liberating the relatively high amount of Glu and Asp.

Some New Squid Products of Gastronomical Value

We have developed a number of prototype products from Danish squid using mantle, arms, and tentacles (Faxholm et al., 2018). As an example, where the focus has been on developing a textural profile that is assumed to be acceptable to Western palates, we have cooked squid mantle both to tenderize the mantle and to preserve it as a confit. By cutting the mantle into thin strips along the long direction of the mantle, which is across the strongest (circular) muscle fibres, it is possible to obtain a product with an appealing curly appearance when the squid strips have been cooked in sunflower seed oil at 85 °C for 35–40 min, depending on the thickness of the mantle. The curling is caused by the difference in the collagen structures at the surface compared with the inner part of the mantle. By adding fat to the very lean squid meat in this preparation, a much smoother texture is obtained compared with equivalent low-fat cooking methods. The curly mantle confit is silky soft and can be served as is with lemon juice, chopped parsley, salt, and pepper (Figure 80.3). This curly squid can also be served cold, like pasta, in a cold salad, or in most ways in which pasta is used.

We believe that, as demonstrated in this chapter, by applying scientific reasoning and methodologies (gastrophysics) along with gastronomic exploration of Nordic squid, it is possible to promote a more varied use of an underappreciated and underused food resource from Nordic waters.

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FIGURE 80.2 Free and total amino acid composition (mg/100 g) of raw squid mantle. Ala, Gly, Thr, and Ser taste sweet, and Glu and Asp taste umami.
REFERENCES


Mouritsen OG. 2012. The emerging science of gastrophysics and its application to the algal cuisine. Flavour, 1, 6.


FIGURE 80.3 ‘Silky squid’ (curly mantle confit) of squid mantle strips. (Courtesy of Jonas Drotner Mouritsen)