Characteristics of the flesh and quality of products of catfishes

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Abstract

Specificities of the structural, chemical, physical and sensory characteristics of the flesh are reviewed and related to different aspects of flesh quality. Potential for processing of catfish is high in terms of mechanization but rather low in terms of processing yields. The variability observed in body conformation traits supports the possibility to improve processing yields by genetic selection. Little is known on the structure of catfish flesh but a higher cohesiveness due both to greater connective tissue strength and probably a greater homogeneity of muscle tissues is observed, compared to other freshwater species. Although the presence of adipose tissues has not been demonstrated, intermuscular adipose tissues contributes with red muscle to lipid deposits in commercial size. Lipid content in catfish flesh increases with age but even at commercial size it is still lower than what is reported in other cultured fish. There is however a tendency in recent years for an increase in lipid content in catfish flesh due to increased lipid content in the diet. Thus, further information on the control of lipid deposits is required in future especially in a view to improve taste and processing yields. The lipid composition of neutral lipids reflects that of the diet with high levels of monounsaturated fatty acids and a low w3/w6 ratio.

Flesh colour is very subtle but it could be controlled either by the use of pigment supplementation in the diet or by rearing non pigmented catfish. Other physical characteristics of the flesh are very stable during the cooking process. Cooked flesh has a relatively low water-holding capacity and a low resistance to mechanical stress (compression, extrusion) thus contributing to the juiciness and tenderness of the flesh.

The sensory characteristics of the flesh are somewhat neutral but consumers are able to detect the specific characteristics of different species such as Channel catfish, African catfish and European catfish. Significant efforts to standardize the sensory evaluation of Channel catfish have been made in the USA but flavor and aroma of catfish seem to be more related to the fish itself than to other factors such as the diet composition. New data is available on off-flavors related to geosmin and methyl-iso-borneol. Specific control of the phytoplankton species which produce these compounds appears to be possible.

Storage on ice affects the flesh acceptability as it does for other fish species, but catfish flesh seems to be stable at least physically during freezing. Traditional processing is used for preservation of the flesh. New processing methods have been tested for the diversification of catfish products or to produce substitutes for other animal products. Catfishes are generally shown to be suitable for processing.

Keywords: Fish culture, feeding experiments, flavor, fish fillets, catfish.

Caractéristiques de la chair et qualité des produits chez les poissons-chats.

Résumé

Les caractéristiques morphologiques, structurales, chimiques, physiques et sensorielles spécifiques de la chair des poissons-chats sont mises en évidence et leurs implications sur la qualité sont étudiées. Les poissons-chats présentent d'excellentes aptitudes à la transformation mécanique mais les rendements sont faibles. L'existence d'une variabilité de conformation corporelle permet de penser que l'amélioration, par sélection génétique des rendements de transformation, est possible. Il existe peu de données sur la structure de la chair des poissons-chats. Celle-ci est caractérisée par une bonne cohésion résultante à la fois d'une grande résistance du tissu conjonctif et probablement d'une plus grande homogénéité du tissu musculaire comparée à la chair des autres poissons d'élevage. Bien que la présence de tissus adipeux ne soit pas démontrée, les tissus adipeux intermusculaires contribuent certainement avec le muscle rouge aux dépôts de lipides observés ches les Siluriformes de taille commerciale.

La teneur en lipides de la chair augmente avec l'âge mais reste très inférieure même aux stades commerciaux à celle de la chair des autres poissons d'élevage. Une tendance récente à l'augmentation de la teneur en lipides de la chair, liée à une augmentation de la teneur en lipides de l'aliment, est observée chez le poisson-chat. Un contrôle de l'état d'engraissement qui conditionne notamment les rendements de transformation et le goût des produits serait donc nécessaire dans l'avenir. La composition en acides gras des lipides neutres reflète celle des lipides de l'aliment avec des teneurs élevées d'acides gras monoinsaturés et un rapport w3/w6 faible.

La couleur de la chair est très subtile et peut être contrôlée partiellement par l'apport de précurseurs de pigments dans l'alimentation ou par l'élevage de souches non pigmentées comme c'est le cas pour le poisson-chat. Les caractéristiques physiques de la chair restent stables à la cuisson. La chair cuite présente une faible capacité de rétention d'eau et une faible résistance mécanique (à la compression et à l'extrusion) ce qui participe à la jutosité et à la tendreté de la chair. Les caractéristiques sensorielles de la chair sont relativement neutres mais les jurys de dégustateurs peuvent détecter les caractéristiques spécifiques de différentes espèces : poisson-chat américain *Ictalurus* sp., poisson-chat africain, *Clarias* et silure européen, *Silurus* sp. De grands efforts ont été faits pour standardiser l'évaluation sensorielle du poisson-chat aux États-Unis. La flaveur et l'arôme du poisson-chat semblent toutefois plus dépendants des caractéristiques intrinsèques à l'espèce que de la composition de l'aliment. Des données nouvelles ont été obtenues sur les "off-flavors" dûes à la présence de composés comme la géosmine et le méthyl-iso-bornéol. Le contrôle spécifique de certaines espèces du phytoplancton responsables de la production de ces composés semble envisageable.

Le stockage dans la glace modifie l'acceptabilité de la chair qui, toutefois, semble stable physiquement au cours de la congélation. Différents types de transformation de la chair ont été développés. Les procédés traditionnels permettent de faciliter la conservation. De nouveaux procédés ont été testés spécifiquement sur le *Ictalurus* sp. pour la diversification de la valorisation des produits à base de poisson ou pour obtenir des produits de substitution d'autres produits animaux. Les Siluroidei présentent une grande aptitude à tous ces types de transformation.

Mots-clés : Élevage de poisson, alimentation, filets de poisson, Siluroidei.

INTRODUCTION

Improvement of fish performance by the control of the main functions (reproduction, nutrition, adaptation, etc.) is exploited by a clear definition of fish flesh quality. In advanced fish industry such as those for salmonids in northern Europe or catfish in the USA but also in traditional fish breeding processes such as those used for cyprinids in central and eastern Europe and in Asia, or milkfish in Asia, more and more emphasis has been placed on the definition and improvement of flesh quality but only once a given level of performance has been reached. In recently developed production areas (flatfish, Sparidae, some Siluridae) the same effort to achieve better knowledge of quality factors in these new products accompagnied the improvement of production itself.

Quality is often seen from a practical point of view *i.e* acceptability of the end product of the production process. However, the quality of these end products is the results of a long chain of processes: production itself which is a combination of intrinsic characteristics of fish and their expression in a given environment, slaughtering, post mortem changes, processing, storage. Basic knowledge on how these different steps affect end product quality is thus required.

Furthermore, the quality of fish flesh covers different complementary aspects. From the consumer point of view there are three important aspects in the quality of a product: safety, nutritional value and sensory characteristics. In cultured fish, the complete control of slaughtering and storage period largely decreases risks of bacterial development although specific risks for consumers due to intensive breeding are still present. Quality definition of cultured fish is thus mainly focused on its nutritional and sensory aspects. The fish industry, fish farmers included, has its own definition of the quality of a product which comprises its processing capability.

These different aspects of fish flesh quality are reviewed from data available in the litterature. We present valuable information on the factors which affect flesh quality and open prospects for its control. This review is devoted to Siluriforms which include a large variety of species. There is however very little published data on Siluriforms and most of it is devoted to catfish. Catfish are thus presented as a reference model and additional information on other Siluriforms is also given.

The characteristics of Siluriforms are specific in terms of body shape, flesh structure and flesh taste compared to other fish. These specificities and their consequences both for processing and for the expression of sensory characteristics are specifically illustrated in this review.

GROWTH, BODY SHAPE AND PROCESSING SUITABILITY

Siluriforms are generally dressed by evisceration, heading and skinning because of aspect (Channel catfish, African catfish) or size (European catfish) of whole fish. The evisceration yield amounts 90% of fresh body weight depending on the species and final dressing yield amounts 60% (*table* 1). The different dressing stages could be mechanized. This is already used successfully with Channel catfish and for the processing of other Siluriforms including European catfish.

The evisceration yield is rather high. It depends mainly on the development of visceral fat which is slight in catfish (2 to 3% body weight) compared to that observed in salmonids. However, large differences in visceral fat development between strains and hybrids (3.5 to 12.1%) have been observed in catfish (Smitherman *et al.*, 1983). The control of fat deposits in the different parts of catfish will be analysed in another chapter but the use of high fat diets does appears to have a dramatic effect on visceral fat.

The yields of other dressing stages (heading and skinning) are rather low and this is mainly the consequence of the conformation (large head) and the thickness of skin (Yamaguchi *et al.*, 1976) of catfish.

Little information is found in the literature concerning the variability of such yields and especially their potential relationship with body shape. The final dress out percentage seems to be more dependent on visceral percentage than on head percentage (Dunham *et al.*, 1983). This is probably related to the priority in the development of adipose tissues at that commercial size. The production of triploid fish with reduced gonad development, at least in females (Chrisman *et al.*, 1983), leads to a significant increase in dress out percentages in large fish (Christman *et al.*, 1983) but not in small commercial sizes (500 g) (Wolsters *et al.*, 1991) and this is also probably due to the larger development of visceral fat at small sizes.

Table 1. – Dressing yields (% body weight) in commercial size farmed silurids.

	Evisceration %	Dressing %	Filleting %	Reference
Channel catfish				
Ictalurus punctatus				
160-190 g		60-63		Webster *et al.* 1992
200-300 g		68		El-Ibiary and Joyce 1978
200-220 g		52-54		Webster *et al.* 1993
400-600 g	87-90	64-68		Dunham *et al.* 1985
450-600 g		64-67		Li and Lovell 1992
460-520 g		58-61		Li and Lovell 1992
480-500 g		55-57	27-28	Wolters *et al.* 1991
610 g		61	31	Clement and Lovell 1994
600-700 g		58-62	32-35	Grant and Robinette 1992
900 g	92		26	Manthey *et al.* 1988
1 300-1 600 g		62-63	36-37	Grant and Robinette 1992
1 580-1 860 g		66-67		Li and Lovell 1992
1 600 g		53		Webster *et al.* 1993
Ictaluridae				
500 g		55-64		Dunham *et al.* 1983
African catfish				
Clarias gariepinus				
Standard fish 1 030 g	92		31	Manthey *et al.* 1988
Experimental fish 646 g	90		26	
Female 630 g	79		39	Hoffman *et al.* 1993
Male 670 g	94		47	
European catfish				
Silurus glanis				
2 650 g	91		38	Manthey *et al.* 1988
1 500-2 500 g	85	65-70	34-43	Proteau 1993
Guyane Silurids				
Arius albicans				
1 600-2 100 g		67-69	49-53	Durand 1977
Arius luniscutis				
4 500-6 500 g		64-65	46-49	

Phenotypic variability in body conformation of catfish has been observed and thought to be related to genetic origin (Dunham *et al.*, 1983, Grober and Van der Bank, 1994). There are large differences between strains of Channel catfish in dress out percentage (Smitherman *et al.*, 1983, Dunham *et al.*, 1983). Within a population, the genetic variabilities of dress out percentage, and of its main component, head percentage, are very low at least in small commercial sizes (El-Ibiary and Joyce, 1978) suggesting few possibilities of direct improvment. The phenotypic correlations of dress out percentage with some indirect characteristics: head length and width, body depth and girth are also low and only body density seems to be a candidate for indirect dress out percentage prediction (Dunham *et al.*, 1985).

One alternative is to breed another species with high dress out percentages such as blue catfish (Grant and Robinette, 1992), white catfish or their hybrids (Smitherman *et al.*, 1983). In these different populations the genetic variability in dress out percentage at harvest could be predicted partially by the variability in some early body traits (head width and depth and caudal width) (Dunham *et al.*, 1983). It is interesting to note that these early body traits are related to relative growth of the head while at commercial size it is rather adipose tissues that would predict dress out percentage. Such indirect criteria could thus be included in a genetic breeding scheme for dress out percentage improvement.

The next processing step is filleting. Almost 50% of the catfish market in the USA is devoted to filleting. Due to the curvature of the vertebral axis in Siluriforms, filleting could not be mechanized easily. The filleting yields are low: 30% compared to other species (salmonids, cyprinids). Some data obtained in European catfish suggest that the filleting yield could amount 40% (Proteau, 1993; Martin and Petillot, pers. comm.). Differences in filleting percentage would however depend on the removal of abdominal fat and on the way of dressing (Wolsters *et al.*, 1991). There is no data on the variability of this yield and thus on the possibilities of improvement of such yield.

There are no large changes in these yields with aging (Silva-Pacheco, 1987). This is an indication that the different parts of Siluriforms grow allometrically to body weight (Dunham *et al.*, 1985). However, as observed in other species (salmonids, cyprinids), the dressing and filleting yields tend to increase in large fish (Heaton *et al.*, 1973; Proteau, 1993; Li and Lovell, 1992). Such scaling effect is the consequence of the development of the muscle mass relative to head part and vertebral axis. Furthermore, one limiting factor in filleting suitability is the development of muscle mass in the caudal part of the fish (Proteau, 1993) rather than muscle development in the anterior part. A significant width in that part of the body has to be reached for a efficient flesh removal. Selection for growth rate and even dress out percentage often results in the development of muscle mass just behind the head, and carp provides a clear demonstration of this effect (Fauconneau *et al.*, 1995). It probably results from an anteroposterior muscle development gradient not only during embryonic and larval development but also during post-larval growth. Selection has thus to be directed on development of caudal part of fish.

CHARACTERISTICS OF THE FLESH

The characteristics of the flesh seem to be related to structure and composition.

Structure of flesh and tissue characteristics

Changes in protein content as well as in lipid content of the flesh result of the relative development of the different tissues which make up the flesh: muscle, connective tissues and adipose tissues. No data is available on tissue development in Siluriforms. It could only be supposed that muscle and adipose tissues have successively or simultaneously a positive growth allometry during a period starting from the post-larval phase up to commercial size as has been observed in other fish (salmonids, cyprinids).

Flesh comprises three different muscle tissues: red superficial, deep white muscle and intermediate pink muscle which differ in their metabolic and contractile properties (Johnston, 1982). These properties are given by the fibre types present in these muscle. Red muscle is composed of slow (slow rate of contraction) oxidative fibre type and white muscle of fast (fast rate of contraction) glycolytic fibre type. Pink muscle consists of an intermediate fibre type (Johnston, 1982). Furthermore, in different fish species, red muscle is a site for lipid storage (Henderson and Torcher, 1987). This has been observed in Channel catfish (Botta, 1974) where the lipid content of red muscle (21% fresh weight) is largely higher than that of white muscle (1 to 2%).

Although there are few studies on this aspect, the originality of catfish (*Ictalurus melas*) muscle seems to be related to the complexity of pink muscle and the occurrence of mosaics in white muscle. Pink muscle seems to be composed of two different layers (Mascarello *et al.*, 1986) which are composed of specific fibre types. Catfish white muscle is classified by Rowlerson *et al.* (1985) as non-mosaic due to its relative homogeneity in terms of size and metabolic and contractile properties of fibre compared to other species. These results have been obtained on young individuals (20-25 cm length) in which muscle is rather immature as indicated for instance by the low ratio between the two myosin alkaline light chains of white muscle LC1f/LC3f (Rowlerson *et al.*, 1985) but it could be a general feature of catfish muscle. Another Siluriform (*Clarias anguilaris*) does not display a wide fibre size distribution (El-Dashlouty *et al.*, 1976). However, a clear mosaic pattern is observed in the white muscle of Heteropneustes fossilis (Urfi and

Talasera, 1989). Although these differences could be related to species differences, it is also known that different factors and especially nutritional status and season affect fibre type distribution. Further studies are thus certainly required but there is some evidence that white muscle in Siluriforms is rather homogeneous compared to other fish species.

Furthermore, the presence of small fibres in white muscle is generally associated with hyperplasic growth. The small fibres are often different in their metabolic and contractile characteristics from large fibres and they are supposed to be new growing fibres (Urfi and Talasera, 1989). If growth process in catfish is similar to other species, the absence of any mosaic pattern suggests differences in the localization of hyperplasic process, probably at the periphery of the white muscle near the pink muscle (Rowlerson *et al.*, 1985) or even making up one layer of pink muscle. Thus, the main cause of variability of white muscle characteristics, growth rate, would affect only superficially the flesh in catfish when it is affected deeply in other fishes.

Finally the innervation of fibres in catfish white muscle is focal but in other species each fibre is innervated by different motoneurones (Rowlerson *et al.*, 1985). The effect of exercise, another cause of variability in white muscle characteristics, could thus differ in catfish. However no published data supports this assumption.

Although the consequences for flesh quality are not known, the possible homogeneity of deep muscle characteristics and the relative stability of these characteristics during the growth process would certainly explain the general acceptance of catfish flesh. It would be important to validate such a hypothesis in catfish and in different Siluriforms.

The connective tissue is inserted between the myomeres and holds the muscles together (Dunajski, 1979, Bremner, 1992). Connective tissue has been studied in fish of rather large size (45 to 65 cm). Its thickness seems to be relatively similar amongst the species (Yamaguchi *et al.*, 1976) although such comparisons have not been made on fish of the same age and it is known that thickness of connective tissue should increase with aging (Bremner, 1992). Some early studies suggest that the collagen content in the flesh of catfish: 7% could be the highest amongst fish species (Sikorski *et al.*, 1984). From the hydroxyproline content of the flesh, it also seems that collagen content of cultured African catfish is lower than that of wild catfish (Hoffman *et al.*, 1993) but this could probably be related to age differences.

The connective tissue of catfish is also strong compared to other fish species and this is also true for the skin of catfish (Yamaguchi *et al.*, 1976). It is probably the consequence of a larger proportion of intermolecular cross-links within collagen. Finally, the susceptibility to thermal denaturation of catfish collagen seems to be higher than that of other species (Yamaguchi *et al.*, 1976; Sikorski *et al.*, 1984) and this is associated with its low proportion of hydroxyproline.

The connective tissues of catfish because of the intrinsic characteristics of collagen therefore ensure the integrity of raw flesh during manipulation. But due to its high thermal sensitivity it could affect other aspects of cooked flesh quality.

Finally adipose tissue has never been studied in itself in Siluriforms. It has generally been studied only in few fish species (Fauconneau *et al.*, 1992; 1995). However, adipose cells can be observed in the flesh between the myomeres and in subcutaneous fat (Fauconneau unpubl.). Lipids in fish can be deposited either in liver, in red muscle or in specific adipose tissues (Henderson and Tocher, 1987). Relative development of visceral fat is not significant in Siluriforms and fatty liver is not observed in these fish. Furthermore, an antero-posterior gradient of lipid contents in fillet or carcass (higher in the caudal part) is observed in many Siluriforms (Jafri, 1973; Shreni and Jafri, 1978; Manthey *et al.*, 1988). By taking into account the similar changes in the proportion of red muscle along the vertebral axis it is suggested that red muscle is responsible for such a gradient.

Chemical composition

General changes in composition during aging are a stabilization of protein content, an increase in lipid content and a concomitant decrease in water content (Degani, 1983). There are no information available on changes in protein composition (protein fractions and amino acid composition) during aging but this variability is generally not very significant in fish (Fauconneau *et al.*, 1995). The amino acid composition of catfish flesh is not very informative even for the nutritive value of the flesh, as they are very similar from one species to another species (Manthey *et al.*, 1988; Hoffman *et al.*, 1993; Clement and Lovell, 1994) (*fig.* 1).

The lipid content in the flesh is low in different catfish species. Recent data always gives however more than 6% lipid (% fresh weight) in the flesh (*table* 2) and belly fat as well as high lipid content in the flesh have been reported (Sheperd and Bromage, 1988). Thus the control of flesh lipid content could be in the future an important aim for quality studies both to ensure a minimum amount of lipid (development of aroma and pigmentation) and to avoid fatty fish. Different factors affect lipid content in Siluriforms as in other fish: body weight, season, feeding, dietary protein and dietary lipid (*table* 2). Large differences in lipid content between strains (Erickson, 1993) and hybrids (Smitherman *et al.*, 1983) are reported. There is a genetic variability in lipid content of the flesh but when measured directly it is rather low and its heritability is lower than 0.1 (El-Itiary and Joyce, 1978) but this data has to be confirmed with current lipid content observed in catfish. Furthermore,

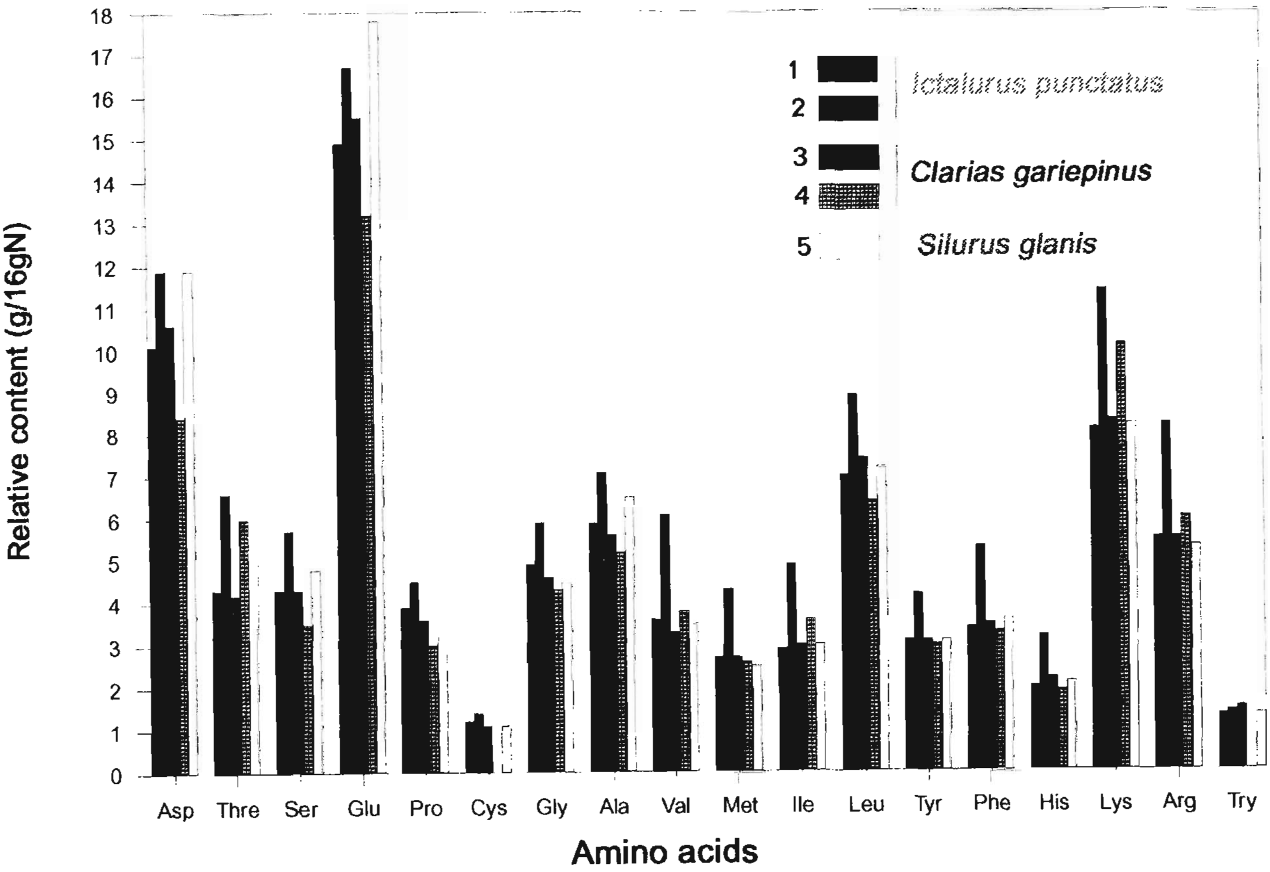

Figure 1. – *Amino acid composition of total protein in* Siluriforms flesh [from (1, 3, 5) Manthey *et al.*, 1988; (4) Hoffman *et al.*, 1992; (2) Clement and Lovell, 1994].

selection for growth rate of catfish is associated with lower lipid content in the flesh (Tidwell, 1988) and this is a rather positive point.

The lipid content in fish flesh is an important quality factor but the fatty acid composition is also important especially for physical stability (melting point of lipid) and for lipid susceptibility to oxidation which affects both aroma and potential rancidity.

The flesh of farmed Channel catfish and African catfish comprises less than 1% phospholipids (Mitchell, 1987; Akoh and Hearnsberger, 1993) which contains over 40% polyunsaturated fatty acids (Erickson, 1992). These phospholipids contain roughly the same content of w3 and w6 fatty acids (w3/w6 ratio: 0.7) (Erickson, 1992). The phospholipid content and composition show the same pattern in wild Channel catfish (Chanmugam *et al.*, 1986) and in marine catfish (Choi *et al.*, 1985; Smith *et al.*, 1990) except for the content of w3 fatty acids which are higher in marine catfish.

The main lipids are neutral lipids with a composition which mainly reflects that of the diet. They contain high levels: more than 49%, of monounsaturated fatty acids (*fig.* 2) (Tidwell and Robinette, 1990, Erickson 1992, Akoh and Hearnsberger, 1993) and their content of w3 fatty acids is low (w3/w6 ratio: 0.1 to 0.2) (*fig.* 3). The proportion of monounsaturated fatty acid increases with body weight (Tidwell and Robinette, 1990).

If fatty acid composition of neutral lipids is mainly controlled by diet composition, other factors can slightly modify this composition. Extrinsic factors such as season (Mitchell, 1986) and intrinsic factors such as aging (Tidwell and Robinette, 1990) and genetic origin (Erickson, 1992) have thus to be taken into account.

Lipids are highly susceptible to oxidation (Erickson, 1992) because of their high PUFA content. The presence of a natural antioxidant such as alpha-tocopherol within the flesh could partially prevent the oxidation process. The tocopherol content could be controlled by the diet (Gatlin *et al.*, 1992).

Finally, the pigmentation of fish flesh is an interesting aspect. The colour of Siluriforms is rather subtle compared to that of salmonids and cyprinids. The grey colour of the flesh and its distribution pattern is rated rather positively by traditional catfish consumers. Yellow/beige/pale pink colours are also found in the flesh of other catfish (*fig.* 4*a*). This specific colour spectrum and homogeneity could be reproduced in farmed catfish

Table 2. – Lipid content (% fresh weigth) in carcass or fillet of commercial size farmed silurids.

	Carcass %	Fillet %	Observations	Reference
Channel Catfish				
Ictalurus punctatus				
Wild catfish		0.5		Chanmugam *et al.* 1986
Farmed catfish		3.0		Chanmugam *et al.* 1986
Farmed catfish		6.8		Akok and Hearnsberger 1993
610 g		7.4		Clement and Lovell 1994
900 g		9.0		Manthey *et al.* 1988 Hearnsberger 1993
300-1 000 g		10.8-13.2	Fish Size	Silva and Ammerman 1993
		3.7-5.4	Strains	Erickson 1992
600-700 g	10.3-10.6	5.8-8.6	Season	Grant and Robinette 1992
1 300-1 600 g	10.9	7.8	Season	Grant and Robinette 1992
500-600 g		5.1-8.1	Ration level	Li and Lovell 1992
460-520 g		6.5-8.3	Dietary protein	Li and Lovell 1992
1 580-1 860 g		8.7-11.0	Dietary protein	Li and Lovell 1992
1 600 g		10.5-11.5	Dietary protein	Webster *et al.* 1993
400-2 000 g		4-9	Dietary lipid	Tidwell and Robinette 1990
African catfish				
Clarias gariepinus				
850-1 050 g	2.0-2.9		Wild fish	Hoffman *et al.* 1992
580-600 g	2.2-3.8		Farmed fish	Hoffman *et al.* 1992
1 030 g	2.8		Standard fish	Manthey *et al.* 1988
646 g	4.2		Experimental fish	Manthey *et al.* 1988
European catfish				
Silurus glanis				
1 500-2 500 g		3.0		Martin and Petillot this issue
2 650 g		4.4		Manthey *et al.* 1988
Others				
Arias thalassinus				
1 500-2 500 g				
1 000-2 000 g		3.2		Smith *et al.* 1990

by dietary supplementation with carotenoid pigments (Smitherman *et al.*, 1988). For a more neutral aspect and for the development of new processes, however a white flesh could be required (Heaton *et al.*, 1973). For that purpose, the rearing of albinos catfish has been developed and their colour is very close to that of white marine fish (Paredes and Baker, 1987). In this fish but also in European catfish cooking has little effect on colour (*fig.* 4*b*), although cooked flesh is more yellowish than raw flesh (Choudrhy, 1977).

QUALITY ASSESSMENT OF THE FLESH

Physical properties of fish flesh

The water holding capacity of fish flesh is generally high compared to meat (Fauconneau *et al.*, 1995). In European catfish, the water holding capacity is lower than that of salmonids but close to that of cyprinids (*table* 3) (Laroche and Marcel unpubl.). It also seems to be lower in Channel catfish than in marine fish (Paredes and Baker, 1987). Such characteristics are generally associated with a greater juiciness of the flesh (Paredes and Baker, 1997).

However, the cooking yield is low and close to that of young, pan size rainbow trout indicating that characteristics of actomyosin in terms of thermo-gelification and water-holding capacity are rather low. Water-holding capacity seems however to increase slightly with age (Heaton *et al.*, 1973) and it could be interesting to relate such changes to muscle growth process.

The mechanical behaviour of Siluriforms flesh is very specific. The tenderness assessed by maximum shear strength or resistance to deformation is higher in raw flesh than that observed in salmonids but similar or lower than that observed in cyprinids (*table* 3, *fig.* 5) and marine fish (Paredes and Baker, 1987). This behaviour could be related to the higher content and strength of collagen in catfish flesh. Cooking has no or little effect on the flesh texture (Bogess *et al.*, 1973; Paredes and Baker, 1987; Laroche, unpubl.). This is rather surprising as in other species, cooking either increases (salmonids) or decreases (cyprinids) mechanical strength (*table* 3).

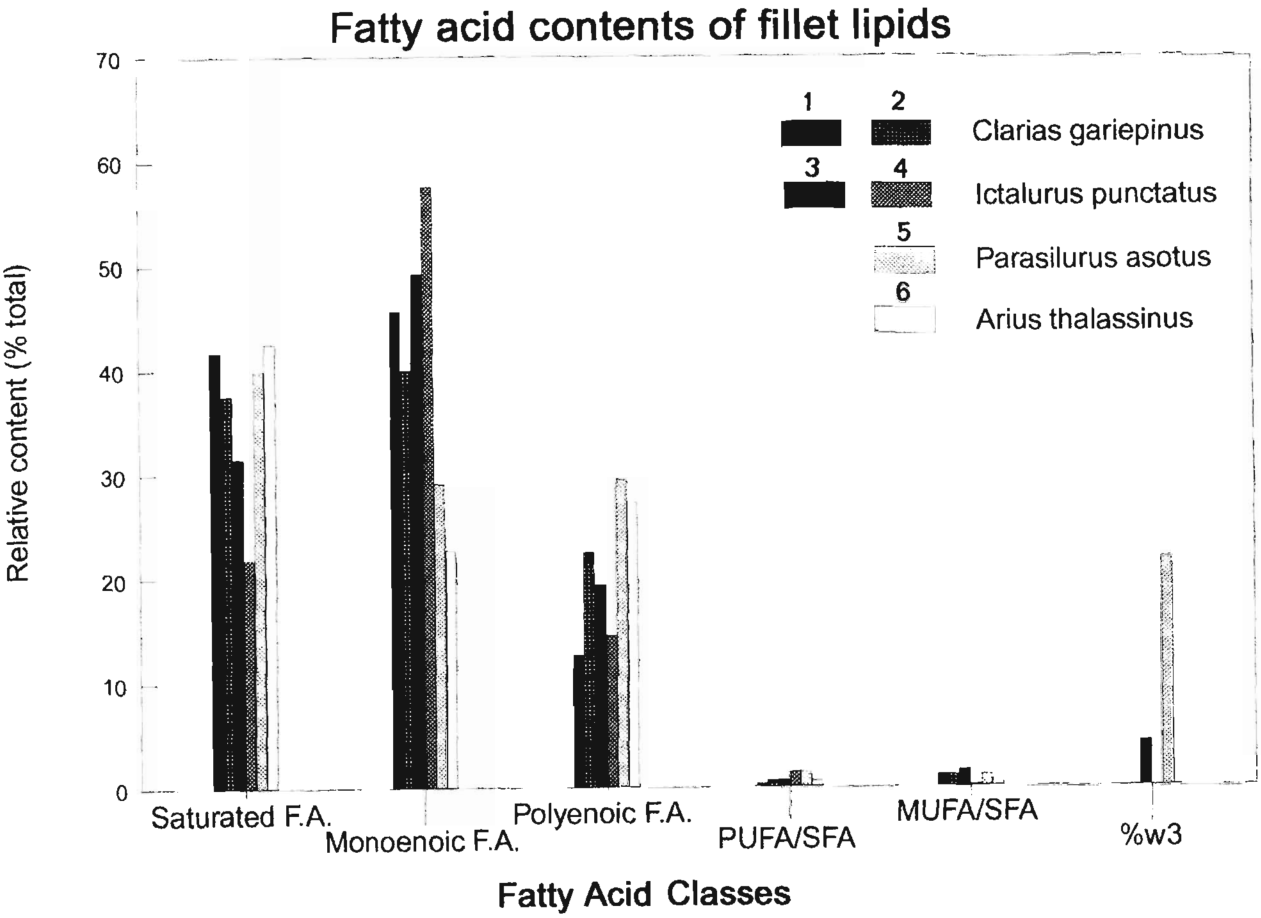

Figure 2. – Fatty acid classes in the flesh of different Siluriforms [from (5) Choi *et al.*, 1985; (2) Manthey *et al.*, 1988; (6) Smith *et al.*, 1990; (4) Erickson, 1992; (1) Hoffman *et al.*, 1993; Akoh and Hearnsberger, 1993].

The changes of Siluriforms flesh due to cooking are thus intermediate within what is generally observed in freshwater fish. It could be emphasized that this is the result both of low thermogelification potential of actomyosin and high susceptibility of collagen to thermal denaturation.

Sensory evaluation and flavor

Whole fresh fish is the main product of the traditional market. Very little is known concerning the criteria of assessment of whole fish quality (aspect, odour) but consumers also eat other freshwater fish like cyprinids in Europe, tilapia in Africa, milkfish in Asia and different pond fish in central USA. Siluriforms are also often associated with sport fishing and these consumers eat fresh fish. There are therefore able to assess fresh fish quality, know how to cook whole fish and appreciate the subtle tasting of catfish.

Generally the sensory evaluation of the quality of fish flesh is not very easy. In farmed fish the odour and flavor are rather subtle, texture is rather soft and juiciness is poor as compared to meat. These characteristics are partially the consequences of the high water holding capacity of fish flesh. Trained panels and specific criteria for each species analysed are thus required. Good sensory analysis could be realized for colour, odour related to freshness, texture and juiciness criteria and this has been used for Channel catfish (Heaton *et al.*, 1973, Botta, 1974, Gibson *et al.*, 1977; Manthey *et al.*, 1988; Silva and Ammerman, 1993), African catfish (Manthey *et al.*, 1988), European catfish (Manthey *et al.*, 1988) and marine catfish (Poulter *et al.*, 1981, Paredes and Baker 1987). Compared to other fish, Siluriforms are generally tougher and have high juiciness. But flavor and aroma are rather mild or neutral compared to other cultured fish or to marine fish. Catfish consumers seem to prefer a mild tasting rather than a strong tasting flavor (Sheperd and Bromage, 1988). Few changes with aging have been observed by sensory evaluation (Heaton *et al.*, 1973).

Two important aspects of sensory evaluation have been especially studied in Channel catfish: the fine description of aroma and flavor and the occurrence of off-flavors. It provides data which is complementary

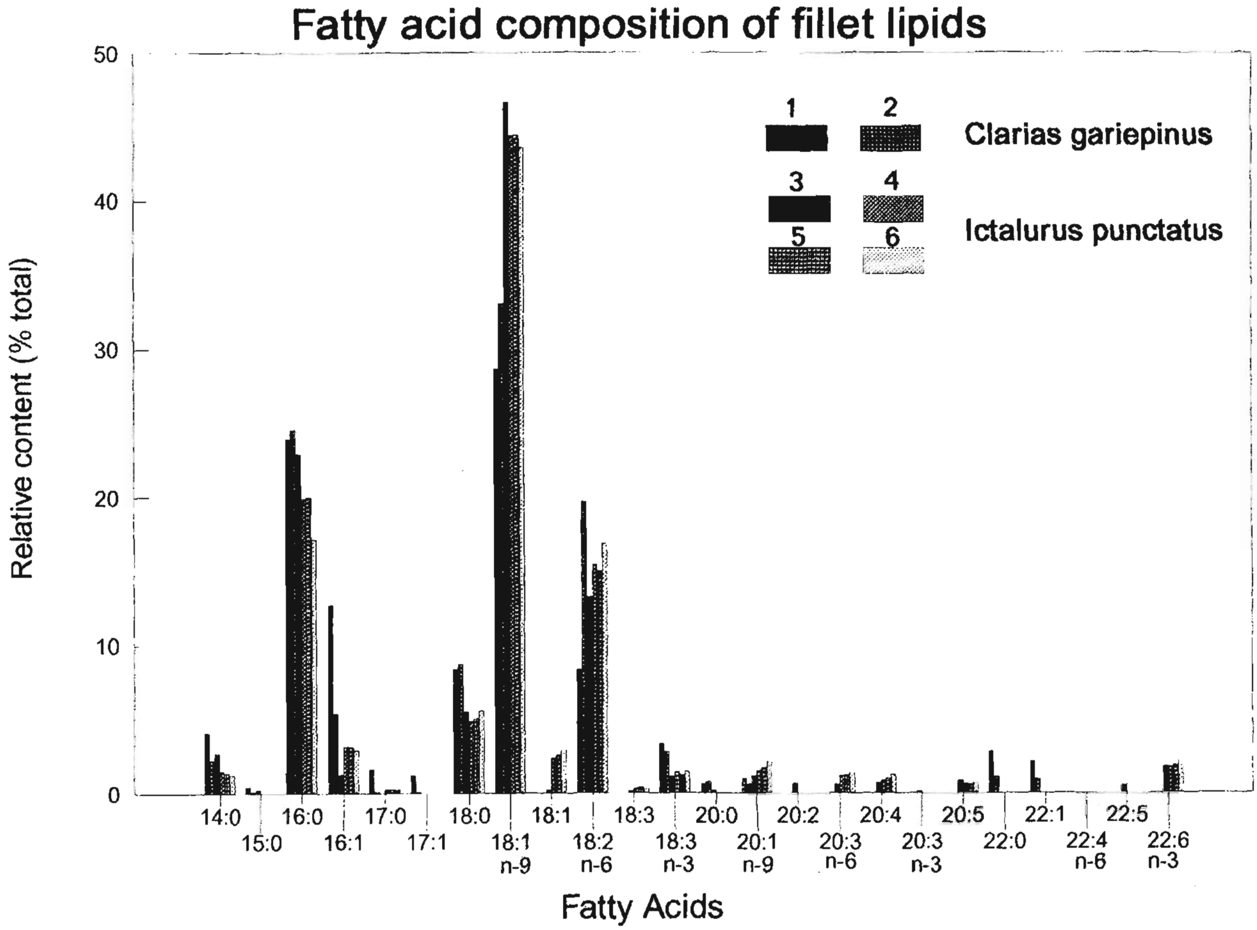

Figure 3. – Fatty acid composition of total lipid in Siluriforms flesh [from (2, 6) Manthey *et al.*, 1988; (5) Erickson, 1992, (1) Hoffman *et al.*, 1993; (2) Akoh and Hearnsberger, 1993; (4) Clement and Lovell, 1994].

to the aroma analysis which has been developed in other species such as salmonids (Josephson, 1990).

The descriptors generally used to describe the flavor of Channel catfish are reported in a lexicon (Johnsen *et al.*, 1987). For aroma, these descriptors are for instance: nutty, chickeny, grainy, fat complex, putrid, rotten plants, cardboard, painty, musty/woody, blue-green. Thus, there are related either to "on-flavors" and desirable flavors, or to rancidity, degradative processes and off-flavors. For taste, the descriptors are: sweet and salty.

This standardized sensory evaluation has been applied to study the effect of diet on the specific flavor of Channel catfish (Johnsen, 1989; Johnsen and Dupree, 1991; Webster *et al.*, 1993) combined or not with a method of sample preparation (Johnsen and Kelly, 1990). On the basis of desirable flavors, trained panelists are able to discriminate between diets containing different feed ingredients. The few significant differences observed are not related to the categories of feed ingredients: fats and oil, fish meal and animal by-products and grains. The authors concluded that the desirable flavors of catfish are related to the fish itself rather than to diet. However such studies have been conducted on small Channel catfish (150 g) which has a relatively low lipid content.

Furthermore, it seems that composition of the lipid in the diet could significantly affect either positively or negatively catfish flavor (Gibson *et al.*, 1976; Dupree *et al.*, 1979) but other descriptors than those related to rancidity have to be implemented. The relationship between instrumental aroma analysis and sensory evaluation has still to be made for catfish in order to make a link between some of the flavors descriptors and precursor compounds present in the flesh (Josephson, 1990). It is for instance important to know if w6 polyunsaturated fatty acid which dominates in catfish flesh is equally susceptible as w3 PUFA to lipoxygenase attack then to autooxidation (Hsieh and Kinsella, 1989). The products of such oxidation processes are volatile organic compounds which are responsible for on-flavor (generally plant aroma). It is not certain that these compounds are related to all specific flavors described

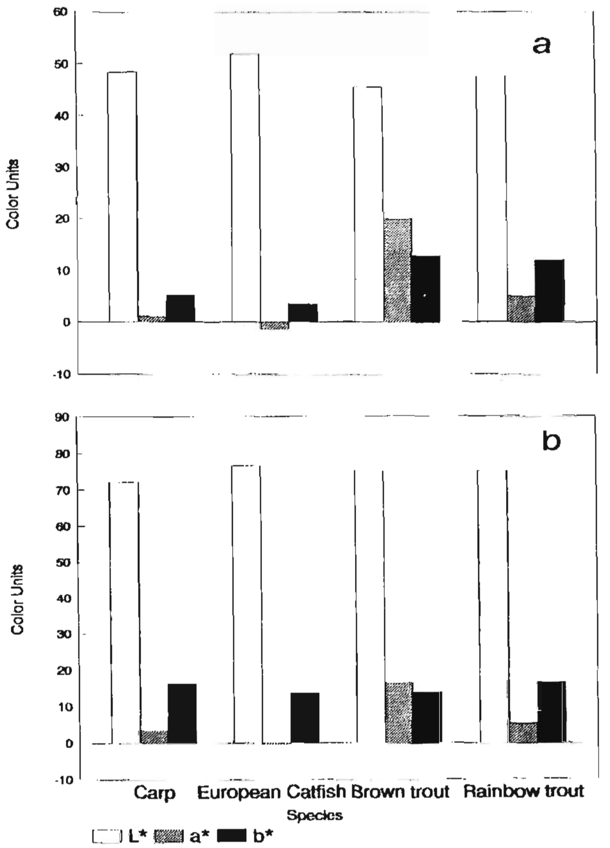

Figure 4. – Instrumental measurement of (*a*) raw and (*b*) cooked flesh colour: L* brigthness, a* red index, b* yellow index in different fish species, see *table* 3 for more details.

for catfish (nutty, chickeny, grainy, etc.). Some of these flavors could be related more to the effect of thermal processing on protein compounds than to lipid decomposition processes (Josephson, 1990).

The occurrence of off-flavor is an important aspect for all pond fish and especially for Siluriforms whose taste and flavor are rather subtle. The products responsible for the main off-flavors such as earthy/musty and blue-green (Lovell, 1983) are respectively identified as geosmin and methyl-iso-borneol (MIB). These two compounds are detected at very low levels by consumers (0.01 ppb) (Spanier and Johnsen, 1992). The uptake of these compounds by fish is very rapid (a few hours when added in the environment) but the clearance when fish are transferred into clear water is very much longer (2 to 3 weeks) (Lovell and Sackey, 1973; Spanier and Johnsen, 1992). They are produced by microorganisms generally found in the ponds or in the tanks: an actinomycete (*Streptomyces*) and a blue green algae (*Oscillatoria*) (Smith, 1988; Martin *et al.*, 1991). Their production largely increases during summer (Amstrong *et al.*, 1986). When one of these microorganisms (*Oscillataria*) dominates amongst the

Table 3. – Water holding capacity and texture of European catfish *Silurus glanis* compared with brown trout (*Salmo trutta*) and carp (*Cyprinus carpio* L.) and pan size rainbow trout (*Oncorhynchus mykiss*).

	Carp	Catfish	Brown trout	Rainbow trout
Body weight (kg)	1.5-1.7	1.5	3.0	0.25-0.3
Raw flesh				
Water-Holding capacity (%)	56-69	68	77	66
Maximum strength (N) Kramer Press	817-1082	1275		328
Maximum strength (N) Comp test	13-15	8.8	8.4	
Cauchy modulus	7.8	3.5	9.1	
Cooking yield (%)	82-85	77	88	77
Cooked flesh				
Water-Holding Capacity % cooked flesh	65	69	75	78
Maximum strength (N) Comp Test	3.5-3.7	8.6	31.3	
Cauchy modulus	1.8-2.0	3.4	13.0	

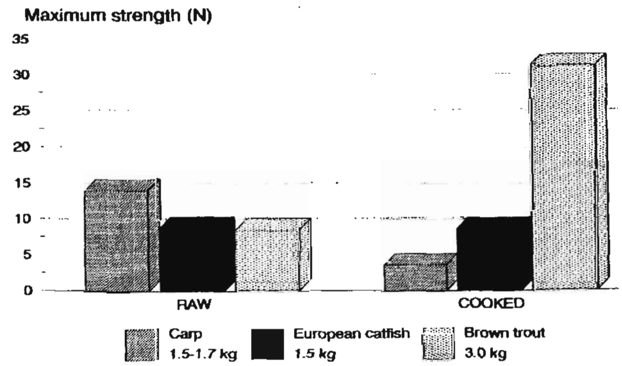

Figure 5. – Maximum strength (in Newton) of the flesh in a compression test in different fish species.

phytoplankton population, there is an increased level of MIB in the ponds (Lorio *et al.*, 1992) and off-flavors appeared within one week in fish.

In order to control off-flavors, regular phytoplankton population analysis could be used to predict the appearance of the two compounds. The use of herbicides to control the algae population itself is not effective firstly because they are not selective and secondly because the off-flavor compounds present in the microorganisms are released into the environment when it dies (Smith, 1988). Other algae population control methods seem to have failed (Smith, 1988). However, the specific control of actinomycete development seems possible by the use of competitive geosmin synthesis inhibitors (Dionigi *et al.*, 1990, 1991).

One interesting point is to learn more about the physiology of these microorganisms and especially about the role of these compounds (Spanier and Johnsen, 1992). The production of MIB and geosmin could play a role in detoxification (mixed function oxidase) processes (Dionigi *et al.*, 1991; Spanier and Johnsen, 1992) within these microorganisms. This data suggests that microorganisms producing off-flavors are subject to stress and this could be related to the fact that off-flavors are often observed in a eutrophic environment. The manipulation of phytoplankton population by controlling the production of these compounds seems to be possible.

Furthermore, due to their structure, these compounds, when present in fish, could be metabolized through cytochrome P450 pathways. If MIB is administered to fish, there are no changes in cytochrome P450 content but significant changes in isozyme patterns in liver and kidney (Shlenk, 1994). This suggests not only that MIB could be metabolized by fish, the metabolites of MIB having no off-flavor effect (Martin *et al.*, 1988; Mills *et al.*, 1993) but also that the detoxification processes of fish are probably affected by MIB or geosmin impregnation.

STORAGE AND PROCESSING

The characteristics described in the previous chapter are those of fresh fish. They could be altered or enhanced during storage or further processing.

Slaughtering method

Little attention has been paid to the method of slaughtering. Classic methods used in catfish (electrical narcosis) but also ice immobilization cause rapid alteration and poor flesh quality especially if fish are not bled. Other methods have been tested, using CO_2 and bleeding. These methods give better results in terms of colour, flavor and texture (Bogess *et al.*, 1973).

Postmortem changes

The flesh of different catfish species when stored on ice are subjected to different alteration processes (enzymatic and microbial) as observed in all fish (Fauconneau *et al.*, 1995 for description of the main steps). In farmed fish, microbial alteration could be controlled and the shelf life of catfish flesh is rather good. Freshness or spoilage of flesh stored in different conditions have been studied (Poulter *et al.*, 1981; Reed *et al.*, 1983; Manthey *et al.*, 1988; Bhattacharyya and Chaudhuri, 1990) to determine the shelf life of different Siluriform species and to develop freshness descriptors. Different lipid oxidation indices have also been tested (Smith *et al.*, 1990). Shelf life is dramatically affected by high temperature storage (Bhattacharyya and Chadhuri, 1990).

It is however more interesting to pay attention to other post-mortem changes. The rigor process has been observed in catfish muscle fibres (*Clarias anguilaris*). An increase in fibre diameter and a decrease in sarcomere length have been described (El-Dashlouty *et al.*, 1976). Rigor onset is a very critical point as in order to avoid gaping phenomena, fish which are processed has to be manipulated before rigor appears. Rigor onset is affected by storage temperature and also by slaughter method. However rigor onset time could not be a critical point for catfish due to the strength of its connective tissue.

At the same time there is a mechanical and enzymatic degradation of different extracellular and intracellular components leading to a softening of the flesh. This have been observed in European catfish (Manthey *et al.*, 1988).

Freezing

During freezing, there is a gradual denaturation of protein, leading to a decrease in water-holding capacity (Fauconneau *et al.*, 1995). Freezing also appears to improve flesh firmness (Bogess *et al.*, 1973; Woodruff, 1988) and this is a rather positive sensory characteristics for Channel and European catfish (Gibson *et al.*, 1977; Martin and Petillot, pers. comm.). Lipid denaturation is also observed during freezing. Polyunsaturated fatty acids from phospholipids are degraded and free fatty acids increase. Peroxide value also increases during freezing (Srikar *et al.*, 1989) but that is not always the case (Silva and Ammerman, 1993). Catfish can be preserved during long periods of time (300 d and more) by freezing (−18° to −20°C) (Gibson *et al.*, 1977; Woodruff, 1988; Srikar *et al.*, 1989; Silva and Ammerman, 1993). However rancid odors and flavors have been detected in fillets of catfish after 2 months of frozen storage (−20°C) under commercial conditions (Freeman and Shannon, 1994).

Processing

The low acceptability of catfish flesh as well as intrinsic characteristics such as holding capacity and texture of the fillet explain why different processes have been applied to catfish (*table* 4).

Traditional processes (drying, salting, smoking) are used to preserve fish or fish fillets (*table* 4). Improvement of these traditional processes have been proposed especially to increase shelf life or to avoid toxic compounds induced by smoking (Faturoti, 1983, 1984, Afoul *et al.*, 1986).

Smoking of Channel catfish in controlled condition gives a product with characteristics close to smoked haddock or chubs. Catfish could therefore be a substitute for these traditional products (Bogess *et al.*, 1973). It has also been applied to European catfish and African catfish (Manthey *et al.*, 1988; Dilemma, 1992) as well as to marine catfish (Turned, 1977). However,

Table 4. – Processing of catfish and sensory evaluation of acceptability of end-product.

	AIMS	SPECIES	ACCEPTABILITY	Reference
TRADITIONAL PROCESSES				
Solar drying Smoking	Preservation	*Chrisicthys nigrodigitatus*	Good High	Faturoti 1984
Solar drying Smoking	Preservation	*Chrisicthys nigrodigitatus*	Good High	Afolabi *et al.* 1986 (but toxic compounds)
Solar drying Smoking	Preservation	*Clarias lazera*	Good	Faturoti 1983
Curing (salting/drying)	Preservation	*Arius thalassinus*	Good	Smith *et al.* 1990
ADAPTATION TO TRADITIONAL PROCESSES				
Oven dried Solar drying	Preservation	*Chrisicthys nigrodigitatus*	Good	Afolabi *et al.* 1986
Smoking	Preservation	*Arius luniscutis* *Arius albicans*	Good	Durand 1977
Smoking	Diversification	*Ictalurus punctatus*	High	Bogess *et al.* 1973
Deep fat Frying Drying Rotating oven	Cooking Diversification	*Ictalurus* *Ictalurus*	High High	Ibrahim and Unklesbay 1986
Canning	Cooking	*Ictalurus punctatus*	High	Paredes and Baker 1987
OTHER PROCESSES				
Protein concentrate	By-product upgrading	*Heteropneustes fossilis*		Hindi and Al-Douri 1987
Restructured product	Diversification	*Ictalurus punctatus*	Good	Burgin and Ammerman 1985
Breaded patties	By-product upgrading	*Ictalurus punctatus*	Good	Burgin *et al.* 1985
Sausage	Pork substitute	*Ictalurus punctatus*	Good	Medeiros *et al.* 1986
Surimi	By-product	*Siluris glanis*	Good	Hermant *et al.* unpublished data

although hot smoking is not really justified as the lipid content of the flesh is not high, smoking is carried out at relatively high temperature (more than 80°C).

The traditional way to prepare catfish fillets, either fresh or frozen is deep-fat frying (Ibrahim and Unklesbay, 1986; Manthey *et al.*, 1988) or canning. The subtle catfish aroma is certainly altered by this process as well as the lipid composition, due to supplementary fat gain by the product.

Other processing methods have been tested on catfish using other cooking processes. Minced or washed flesh have been developed to produce steaks, reconstructed products, sausages or nuggets (*table* 4). The aims of such processes are to obtain substitutes for other animal products. In every case, catfish flesh demonstrated a great ability to processing. This is due to its rather neutral characteristics and its homogeneity but probably also to the suitability of fish actomyosin for thermogelification. The effects of certains factors such as reconstructed product mixing time (Abide and Silva, 1990), the addition of polyphosphate or salt in patties (Burgin *et al.*, 1985), the effect of salt in sausage (Medeiros *et al.*, 1986) on the quality of the final product have been assessed. The changes in terms of firmness or toughness suggest the involvement of actomyosine properties. Furthermore, there have been few studies of catfish pulp valorization probably because of the low thermogelification ability of actomyosine compared to other fish.

CONCLUSION

Although catfish farming is well developed, there is a lack of data concerning their intrinsic characteristics relevant for quality. For instance, little is known concerning the variability of processing yield (dressing and filleting) and more particularly genetic variability and correlation with body conformation traits. Less is known of flesh tissues and protein components. Thus basic knowledge of the characteristics of the flesh involved in the great stability of the flesh and its suitability for processing is lacking. The flesh itself is rather neutral and flavor is mild making it therefore very acceptable if off-flavor compounds are not present. Furthermore thanks to the relative resistance of the flesh during processing or freezing and its neutral flavor, catfish flesh could be processed as a substitute for other animal products.

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