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Fish descalers: A review

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Abstract
Removal of fish scale also called as descaling is considered as one of the most important unit operation during pre-processing of fish. Generally, the descaling of fish is performed in a manual operation. This is not only a time consuming operation but also frequently causes harm and wounds to the hands of persons involved in performing the task. Designing of fish de-scaler will pave way for reducing the human drudgery and also hygienic handling of fish. In this context an effort was made to review the information available on the broad topics such as existing fish descaling practices, types of fish scales, morphology of different types of fish scales, commercially available fish de-scalers, patents available etc. Publications describing such studies were obtained from all peer reviewed sources.

Keywords: scale removal, post processing, fish processing, descaling

Introduction
Recent statistical data reveals that the global per capita fish supply to about 16.7 kg per year. Being second largest producer of fish in the world after China India is contributing 5.43% of global fish production. The total fish production during 2015-16 is 10.79 million metric tonnes (DADF 2016-17). Fish provides a good source of high-quality protein and contains many vitamins and minerals. Research over the past few decades has shown that the nutrients and minerals in fish, and particularly the omega 3 fatty acids found in several fishes, are heart-friendly and can make improvements in brain development and reproduction. Before the fish is ready for preparation of various delicious food this needs to undergo series of pre-processing operations such as washing/ cleaning, cutting of fins, descaling, beheading, evisceration, deskinning, filleting, slicing of whole fish into pieces etc.
A fresh, hygienically cleaned, well-scaled fish with minimum distortion get preferred by the consumers for further operations in making various food preparations or packaging. Scales are prominent outgrowths of skin, or epidermis, with numerous mucus glands found on fish body. The freshwater fishes prevalent in the Indian fish markets such as rohu, catla, mrigal, silver carp and grass carp have prominent scales and their manual descaling is very difficult. The operation of descaling in the commercial plants or at retailers is carried out predominantly by indigenous tools (Fig.1) which are neither safe nor efficient for descaling operations. It was estimated that manual descaling of larger fishes requires almost 50% of the total time necessary to produce beheaded and gutted fish without fins (Kowski & Dutkiewicz, 1996) [5].

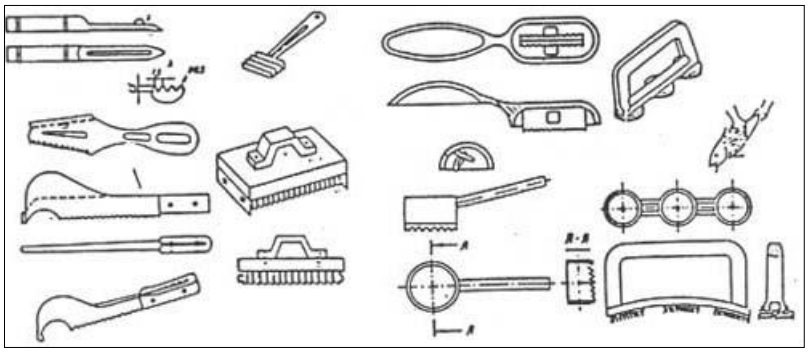
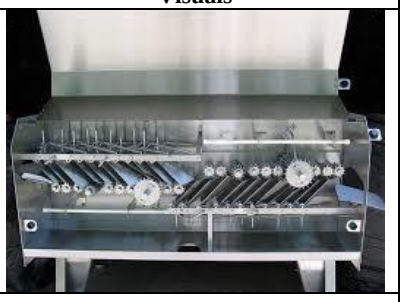
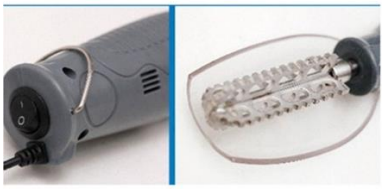
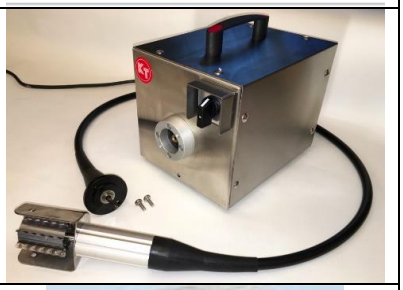
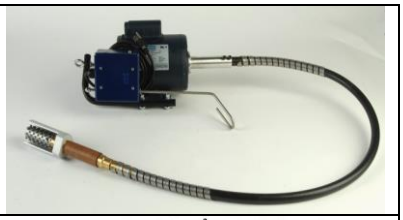
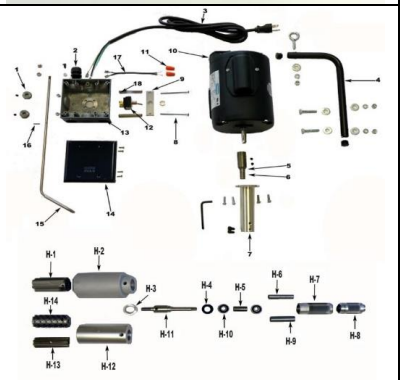
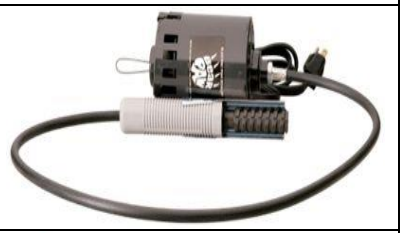
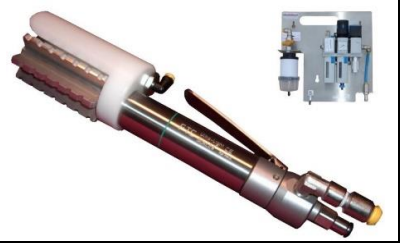


Fig 1: Hand operated tools for fish descaling (Adapted from: Kowski and Dutkiewicz, 1996) [5]

In this context, design and development of a fish descaling machine is need of the hour to not only to hygienically handle food but also to increase the speed of descaling process, reduce the drudgery and improve the safety of operation. To gather knowledge on fish descalers information was collected from several sources and includes commercially available fish scalers, patents and research papers. On our journey of search, we found several companies in abroad deals with automatic fish descaler. To name few includes Trifisk Manufacturing, Uftokuyi, Jiaozuo Zhoufeng Machinery Co. Ltd, ZZ Allance Manufacturing Co. Ltd, Food Machinery of America etc. They have been cited in this section (Table 1). Also, there are enormous patents those have been filed to serve the operation of descaling a fish. There are several types of products that these patents claim depending on the type of usage of the product whether for large food processing industries or for cottage/ small enterprises or even just for household and restaurants purpose.

Table 1: De-scalers available in market

S. No	Name of the machine	Descrciption	Visuals
1	Simor Fish Descaler	Suitable for descaling wide range of fishes. It can handle 125 small size fishes around a minute. Power Requirements: 208/220/380/440/55 Water Requirements: approx 241 kPa (35 lbs pressure) Made up of brushed finish commercial high grade stainless steel cabinet and feeding table.	
2	TOKUYI fish scalers	Powered by 4.8V NI-MH battery for home use or 12V Li-ion battery for professional use 100%Waterproof, IP7 portable and rechargeable	
3	Jiaozuo Zhoufeng Machinery Co. Ltd	Only preferable to use as the household purpose or domestic usage	 
4	KT-S	Handheld setup, usable for domestic / cottage industry	
5	ZZ Allance Manufacturing Co. Ltd	only preferable to use as the household purpose or domestic usage	

6	Fish scalers- Food Machinery of America	heavy duty performer for descaling of fish as commercial use, designed for continuous use in commercial fish processing operations	
7	Northrock	Similar to fish scalers of food machinary of america with minor changes in design aspects.	
8	Zhengzhou Azeus Machinery Co. Ltd	an automated machine and has the capacity to scale all kinds of fish and there is no any restriction for the size of the fish to be fed (not for commercial use)	
9	Bear-Paw Fishing Tackle	3 variants for scaling fishes. One is Electrical Fish Scaler (EFS) (domestic) Heavy Duty Electric Fish Scaler (HDEFS) (domestic) The third variant is Power Drive Fish Scaler (GFS) (industrial use)	
10	Trio FTC	Heavy duty descaling machine for commercial use but has an advantage of being light of only 700 gm, This all makes the job easy and comfortable	

The descalers which are meant for industries take much space and need regular maintenance for a mass production. To cater the need of medium level users, the patents have suggested portable but a moderate rate of production whereas the last category customers the inventors suggested, a manual tool to handle one fish at a time with almost no maintenance cost.

Design of fish descalers also needs not only the mechanical part but also the biological part. Biological part here refers to fish scales. Through understanding about the type of fish scales and morphology of different type of fish scales is also paramount importance in designing the descalers We found a mere lacking of information on this by the designers leading to the inferior quality machine development.

A number of studies on fish scales have been conducted addressing the structural arrangement, and collagen formation and orientation. Most fish scales have type I collagen fibers and calcium-deficient hydroxyl-apatite, similar material components to other hard tissues such as bones and teeth. This combination of collagen and hydroxyl-apatite layers allows the fish scale to have a high penetration resistance (Saha A *et. al.* 2006) [12]. They have a laminate composite structure (Fig. 1) composed of an external mineralized layer and internal lamellae with thickness of 50–60 µm each and composed of collagen fibers with ~1 µm diameter. The alignment of collagen fibers is consistent in each individual layer but varies from layer to layer, forming a non-orthogonal plywood structure, known as Bouligand stacking.

Micro-structural analysis also reveals that the scale has a rugged circular concentric pattern on top to provide advantages associated with hydrodynamic, unlike the inner part of the scale that is in contact with the dermis which presents a smooth surface. Thus all these micro-structural and

mechanical characteristics are used by fish as drag reduction system, mobility and increase protection against predators, which are desirable features in engineering applications through the design of de-scaling devices.

Descaling of fishes

Fish body surface is covered with thin scales, an outgrowth of skin with mucus gland that overlaps each other like the shingles of a roof. Fish post-harvest processing includes several preprocessing operations such as washing/ cleaning, cutting of fins, descaling, beheading, and evisceration, deskinning, filleting, slicing of whole fish into pieces etc. In unorganized fish marketing arrangements which are prevalent in India and other developing countries, the retailers carry out these preprocessing operations with their indigenous tools just prior to sale. This lead to injury to the person involved in the operation. When compared to marine fishes, the scales of the fresh water fishes are difficult to remove which necessitates the use of power operated descalers. Manual descaling of freshwater fishes such as rohu, catla, mrigal, silver carp and grass carp is even more difficult compared to marine fishes due to the presence of prominent scales on their body.

Existing fish descaling practices

Blanching is considered as one of the pretreatment to improve descaling efficiency. This is performed by dipping the fish in boiling water then scaling by hand with motions perpendicular to the long body axis (Kowski & Dutkiewicz, 1996) [5]. The operation of descaling in at retail outlet is carried out predominantly by indigenous tools (Saha *et al*., 2006) [12] with or without blanching. In case of fish processing industry some of the preprocessing operations are carried out using machineries. It was estimated that manual descaling of larger fishes requires almost 50% of the total time necessary to produce beheaded and gutted fish without fins (Kowski & Dutkiewicz, 1996) [5]. Some of the existing de-scaling techniques are listed below.

Garden Hose Technique

Salmon and trout fish scales can be easily removed in this method. This method is quick and effective but fairly messy too. This technique employs garden hose with a nozzle to get a strong narrow stream of water to descale the fish. The major disadvantage of this technique is scattering of fish scales everywhere.

Pot scrubber technique

Stainless steel pot scrubber is an effective and quick way of literally scrubbing out the scales from fish. These scrubbers are a balled up bundle of round stainless steel ribbons. After descaling process, the scrubber is to be rinsed thoroughly to remove all the scales and slime which are embedded deeply into the scrubber to avoid stinking smell emanating from the pot scrubber.

Knife edge technique

A butter knife or fillet knife is used to scrape off the scales from each side of the fish.

Stainless steel brush style fish de-scaler

Scales from heavy scaled fish such as bass is easily removed using stainless steel brush style fish de-scaler. It is simple and effective to use. The de-scaler is moved forward from the tail to the head to scrape off the scales on either side. A similar tool made of spring and a curry comb which is used for brushing horses or pets is also used for this purpose.

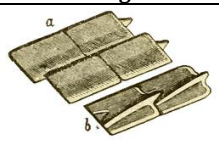
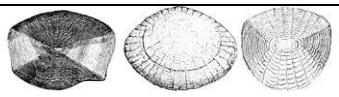
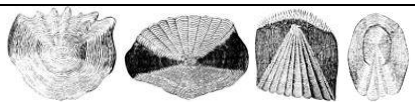
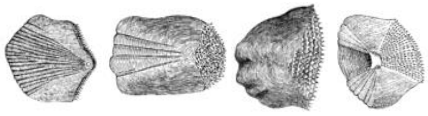
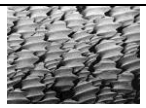
Automatic or electric fish scaler

These are power assisted tools that take away all the elbow grease out of scale removal and really speed up the process. The device generally consisting of power batteries, descaling tool and a transparent cover to prevent the scattering of fish scales.

Fish scales

Different types of fish scales are found in variety of fishes. While thick bony scales are the identity of ancient fishes, modern fishes have evolved with thin and flexible scales for more agility. Following types of scales (Table 2) are found in living and extinct fishes.

Table 2: Types of scales in different fishes

Type of scales	Type of fishes	Image
Ganoid scale	Sturgeons, paddle fishes, gars, bowfin, and bichirs.	
Cycloid scales	Fish with soft fin rays, such as salmon and carp.	 Bream Loach Minnow
		 Grayling Bleak Gudgeon Pike
Ctenoid scales	Fishes with spiny fin rays, such as the perch-like fishes	 Goby Flathead Scat Emperor
Placoid scales	Sharks, Rays, and chimaeras.	 Electron microscopic image of placoid scales

Cosmoid scales

Cosmoid scales are not present in living fishes. They were found in lungfishes and some fossil fishes. It is similar like the one present in crocodiles and protects the body like thick bony blocks. A cosmoid scale consist of a thick layer of dentine material called cosmine covered on the surface by another hard proteinous layer called vitrodentine. The surface of the cosmoid scale is present in the pits (lacunae) and canals (canaliculae) pattern. A thick layer of spongy bone that carries blood vessels for the growth and nourishment of the scale is present under the cosmine. Closer to the fish body soft and spongy lamellar bone called isopedine is present.

Ganoid scales

They are thick, rhomboidal scales. The surface of ganoid scale is coated with ganoin, a hard enamel-like dentine material having lacunae (pits) and canaliculae (fine canals) forming the surface sculpture. Bulk of the structure is made of the dentine-type bone and a lower layer that is called isopedine or lamellar bone. Two variants such palaeoniscoid having dentine-type bone along with isopedine and lepidosteioid having only isopedine are existing in this type of scales While the earlier occurs in ancient fishes like *Polypterus* the latter occurs in modern fishes like Amia and *Lepidosteus.*

Cycloid and Ctenoid scales

Modern teleosts have these types of scales. It is characterized as thin, strong and extremely flexible structure. They are larger in size, oval in shape and made of only isopedine along with an underlying layer of collagenous fibres responsible for providing the required strength and flexibility. Teeth like system present at the base of the ctenoid scales helps them to fix firmly in the skin tissue.

Placoid scales

They are characteristics of cartilaginous fishes (Chondrichthyes) and are hard and microscopic in size. The scale is made up of dentine and the exposed surface of the scale is covered with a hard enamel layer. During the development of the scaledermal papilla sits in the pulp cavity present in the skin surface. Placoid scales resemble like a tooth and for the same reason, teeth of sharks are referred as modified placoid scales. As noted earlier they are anchored in dermis and are replaced throughout life.

Components of fish scale

Type I collagen fibers and calcium-deficient hydroxyapatite are the two major components of any fish scales (Fig. 2). The collagen fibers arrange themselves in different orientations to form a plywood structure and are usually densely packed lamellae (Zylberberg *et al*., 1992; Weiner and Wagner, 1998) [20, 18]. Both orthogonal and double twisted plywood patterns are reported. This plywood structure has been proposed to form a Bouligand arrangement, named after Bouligand (1972) [2] who studied it extensively. The thickness of the scale depends on the dimensions of the laminates and varies with fish species. Lamellae of P. *reticulata* (guppy) are ∼1 μm thick and in case of C. *auratus* (goldfish), they are around 5 μm (Bigi *et al*., 2001) [1]. The angles between lamella layers also found to vary from 36◦ for teleosts, to 90◦ for *Poecilia reticulata* and *Pagrus major* (Zylberberg *et al*., 1988) [21].

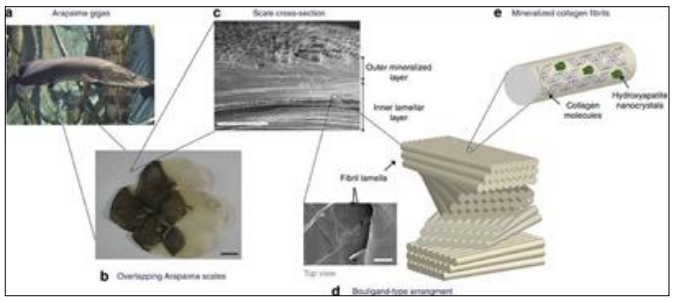


Fig 2: Structure of arapaima fish scales. From Zimmermann, E. A. *et al*. 2013 [19]. Nature communications.

Morphology of fish scales

Scales have been a key form of protection for fish for hundreds of millions of years. The most studied fish scales may be categorized into four types: placoid, cosmoid, ganoid and elasmoid. Arrangement of collagen fibers and hydroxyapatite in each of them are different. (Helfman *et al*., 2009) [6]. Scales from the *Arapaima gigas*, the tarpon (*Megalops atlanticus*) and the carp (*Cyprinus carpio*) were compared in terms of the stacking sequence of individual plies and their microstructure (Sandra Murcia *et al*., 2017) [13] and reported that carp and tarpon exhibit a Bouligand structure with relative rotation of 75° between consecutive plies. The arapaima scales exhibit a cross-ply structure, with 90° rotations between adjacent plies. (Fig. 3).

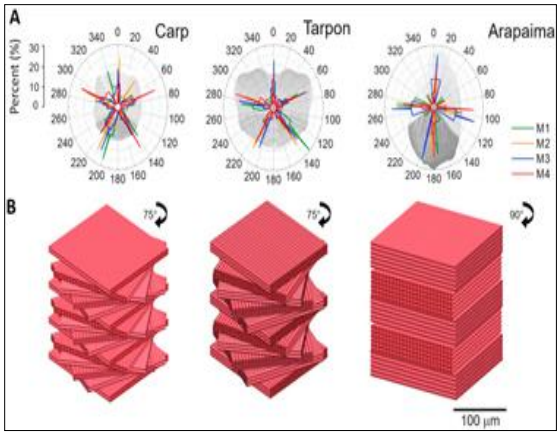


Fig 3: Stacking sequence and microstructure of Scales from the Arapaima gigas, the tarpon (*Megalops atlanticus*) and the carp (Cyprinus carpio)

The fish scale of Pagrus major has an orthogonal plywood structure of stratified lamellae, 1-2 micron in thickness, consisting of closely packed 70- to 80-nm-diameter collagen fibers. X-ray diffraction, energy-dispersive X-ray analysis, and infrared spectroscopy indicate that the mineral phase in the scale is calcium-deficient hydroxyapatite containing a small amount of sodium and magnesium ions, as well as carbonate anions in phosphate sites of the apatite lattice (Zylberberg *et al*., 1992) [20]. A study was conducted to investigate the spatial distribution of structure, chemical composition in mineralized fish scales of the species, Atractosteus spatula by Sherman *et al*., 2016 [14]. High resolution SEM imaging of a fracture surface revealed that the outer layer contained oriented Nano rods embedded in a matrix, and that the nanostructure of the inner layer contained fiber-like structures organized in a complex layered pattern.

Arapaima gigas, a fresh water fish, scales (Fig. 2) consist of a hard, mineralized outer shell surrounding a more ductile core.

This core region is composed of aligned mineralized collagen fibrils arranged in distinct lamellae. Bouligand-type (twisted plywood) arrangement of collagen fibril lamellae has a key role in developing their unique protective properties (Zimmermann *et al*., 2013) [19]. The scale structure of teleost fish (Fig. 4) typically displays a quasi-periodic pattern comprised of alternate rows of overlapping scales running over the length of the fish (Fig. 4a and 4c). In the simplest description the scales can be characterized by their shape, size and overlapping distance (Fig. 4b and 4d) (Browning *et al*., 2013) [3]. Although size of the fish scales significantly varies among species, normalized overlapping distance within a single row of scale is remarkably consistent. For instance, the ratio r of the scale spacing to the length of a single scale was comprised between r=0.2 for the milkfish and r=0.3 for the mullet (Fig. 4c and 4d). Striped bass and the white perch displayed intermediate configurations with r=0.25. Individual scales are attached to the underlying dermis by small pockets of skin, which overlap approximately half of the scale length (Fig. 4d). These pockets are characterized by an intricate net-like structure supported by a soft elastic film (the dermis) that gives the skin its high deformability. More importantly, these pockets function as elastic sleeves for individual scales (Fig. 4d) providing resistance to their out-of-plane rotation as the overall skin bends.

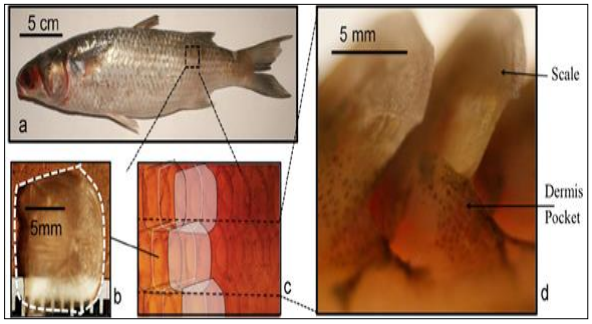


Fig 4: Scale connection with dermis
(a) Overall fish (b-c) Close up scale showing their arrangement (d) magnified view of single layer

Mechanical properties of the fish scales

Bruet *et al*. 2008 revealed materials design principles present in the penetration resistance of the ganoid scales of *Polypterus senegalus*, a small fish that reaches only approximately 200g in mass and 20 cm in length. Its scales have multiple layers, each with unique properties, deformation mechanisms, and a specialized manner in which cracking and failure occur in order to absorb energy and protect the fish. Song *et al*. 2011 [15] demonstrated how the structure of the ganoid scale provides toughness, penetration resistance and non-catastrophic pathways for energy dissipation. Mechanical properties of fish scales from Pagrus major was studied by Ikoma *et al*, 2003 [7]. The tensile strength of the scale is high (approximately 90 MPa) because of the hierarchically ordered structure of mineralized collagen fibers.

Mechanical failure occurs by sliding of the lamellae and associated pulling out and fracture of the collagen fibers. In contrast, demineralized scales have significantly lower tensile strength (36 MPa), indicating that interactions between the apatite crystals and collagen fibers are of fundamental importance in determining the mechanical properties. The micro indentation hardness of the external layer of the Arapaima gigas scales was reported as 550 MPa which is considerably higher than that of the internal layer (200 MPa) confirming the higher percentage of calcium is in the external layer. Further Tensile testing of the scales carried out in the dry and wet conditions showed that the strength and stiffness are hydration dependent and the elastic modulus is equal to 0.26, approximately ten times higher than that of bone (Lin *et al*., 2011) [8].

Fish De-Scaling Machine (recently)

The Central Institute of Fisheries Technology (ICAR) has recently designed and developed a fish descaling machine for removing the scales of fishes in batches. The operation of the machine can be extended for removal of scales from all types of marine as well as fresh water fishes. The descaling machine is based on a new design equipped with a perforated rotating drum and an induction motor of variable frequency drive. The drum of the descaling machine has a capacity to load 10 kg fish. The time of operation and rpm of the drum has been standardized for each species under different size categories for the efficient removal of scales. The rpm of the drum can be adjusted at minimum of 2 rotations to a maximum of 80 rotations per minute. Trials conducted have shown that 98% of the scales can be removed using descaling machine. This is a batch process and the material can be loaded and unloaded easily and only one person is required to operate the machine.

Designed and fabricated different models of Fish De-scaling machines. They are (1) Variable speed Descaling machine, 10 Kg capacity, fitted with 1.5HP induction motor and a Variable Frequency Drive (VFD) to vary the speed of the drum depending on size/ variety of fishes (2) Table- top De-Scaling Machine, 5 kg capacity, with constant drum speed and (3) Hand operated Low cost fish descaling machine.

Slicing machine with a circular cutting wheels (240 mm in Diameter) (Odior A. O, 2012) [11]. Spaced 6.5 mm apart of maximum 6 numbers having a cutting rate of 4 seconds capable of slicing 2.673 t/h as 5 mm slices is a viable solution along the consideration of hygienic practices required for highly perishable fish industries. Thus the reviewers suggest a continuous and circular motion will yield a greater production when used with pin type tools instead of flat tools or blades.

Bykoeski P *et al*. (1996) [5] had suggested the fish processing along with circular and continuous motion of circular blades (20 – 40 fishes per minute) will be a fruitful solution of hygienic steaks of average size between 25 to 45 mm. Thus the reviewers suggest a continuous and circular motion will yield a greater production used with pin type tools instead of differently designed tools, cutting and slicing blades.

Conclusion

This review analyzed the data technically which includes morphology, tools and available machines in the market. Hence the review suggests to go for a "Portable and economically viable semi-automatic machine - de-scaler" to fulfill the increasing demand of cottage level fish processing industry as well the domestic sectors.

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