Development of meat-bone separator for small scale fish processing

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Abstract The belt and drum type meat-bone separator was developed for small-scale fish processing and evaluated using Tilapia fish (*Oreochromis mossambicus*) in terms of capacity, yield, percentage yield, bone content, colour and power consumption. It consists of a perforated drum (3 mm), single phase electric motor, speed reduction gear box and drive system. The machine was evaluated using two food grade belt viz., natural rubber (Belt A-35 shore) and canvas belt (Belt B-65 shore) for three drum speeds. The machine capacity was in the range of 45.59 to 68.54 kg h⁻¹ for belt A with a yield of 1.148, 1.069 and 1.066 kg, and 49.13 to 78.13 kg h⁻¹ for belt B with a yield of 1.253, 1.312 and 1.269 kg at drum speeds of 14, 20 and 24 rpm, respectively. For belt A, the highest yield (1.148 kg) was obtained at 14 rpm drum speed which was 63.78% on dressed weight basis and for belt B, the highest yield (1.312 kg) was obtained at 20 rpm drum speed which was 72.89% on dressed weight basis. The increased number of passes for meat recovery increased the chances of insertion

of bone fragments into minced meat and decreased the colour values (L-a-b). The total energy consumption did not vary significantly.

Keywords Meat-bone separator · Deboner · Meat yield · Bone content · Colour

Introduction

Fish is a rich source of animal protein and polyunsaturated fatty acids which have well defined nutritional role in diet. The health benefits associated with fish consumption have resulted in a favourable consumer image for fish products. Efforts to meet the increasing demand for fish products resulted in an increase in the world fish catch from 85 Mt (in 1985) to 143.6 Mt (in 2006). Presently, India is the third largest producer of fish with total production of 7.12 Mt in 2007–08 (FAO 2008).

Certain issues viz., higher cost of equipments, lack of steady supply of high quality raw material, increased production cost and lack of steady market for fish and fish products affect the utilization of the large quantity of under-utilised and by-catch fish species in India to commercial level (Venugopal 1995). One possible way to utilize such fish species is through isolation of meat and the development of value added products such as surimi and surimi-based products, sausages and fermented products. (Venugopal and Shahidi 1998). There are many techniques available for meat-bone separation such as manual, chemical, bio-chemical, and physical and mechanical. The manual method of meat-bone separation was inefficient, time-consuming and more expensive (Newman 1981). The use of various proteolytic, collagenolytic and electrolytic enzymes has been suggested (Rose 1974) but the control on

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meat separation and enzymatic inactivation in the minced products are the critical factors in chemical method. The use of dilute acids and alkalis was effective (Young 1975) but leads to appreciable breakdown of the protein as well as dissolving bone, especially with acid treatment. The thermal techniques (Duckworth et al. 1969) lead to loss of binding capacity of the meat. Stamp type deboners (Suwanrangsri 1987) are mainly useful for batch operation. Butchers grinding machines would fit in the low investment requirement, but the resulting product proved to be unacceptable due to the quantity of small bones remaining in it and its poor organoleptic properties (Booman et al. 2010). The different mechanical meat-bone separators with different techniques are available, but most of them are of larger capacity and expensive (Graham 1984), and are not affordable to small entrepreneurs and small scale fish processors.

In order to overcome aforementioned problems, this study was undertaken the development of meat-bone separator for the under-utilized and low value fish to meet out the demand of small and medium scale fish processors in India and to fulfil the feasibility of sustainable operation.

Materials and methods

Principle of meat-bone separator operation

The meat-bone separator was developed based on counter rotating belt and drum mechanism in which dressed fishes were fed to counter rotating belt and perforated drum and it gets squeezed through the holes into the cylinder under the pressure applied by the conveyor belt partially encircling the cylinder (about 35% of the cylinder's perimeter) while bones and skin were retained outside of the drum and ejected through a discharge chute.

Design and development of meat-bone separator

As shown in the Figs. 1 and 2, the machine composed of single phase motor, speed reduction gear box (30:1), food grade stainless steel (SS-306 L) drum of 3 mm perforation, conveyor belt (1310×150×20 mm) and drive system. Chain and sprockets were used for transmitting the drive from gear box output to the drum shaft on which the perforated drum was mounted with the help of convenient locking unit (locking plate) for easy mounting of the drum on the drum shaft. A pair of spur gears was used for transmission of drive to conveyor belt and changing the direction of the conveyor shaft in the direction opposite to that of rotating drum shaft. The different components such as drum, conveyor belt, rollers, bearings and drive system

were used for the fabrication of the belt and drum type meat-bone separator. The design consist of determination of power and speed requirements of machine and design of the drive system components viz., Chain and sprockets (Bhandari 1997), spur gear, shafts, coupling which were carried out using the standard design procedures (Khurmi and Gupta 2005). As the pressure between drum and belt is the dynamic factor which varies based on the surface characteristics of drum as well as on the nature of raw material, the power and speed requirements of the machine were calculated on the basis of torque coming at the end of locking plate attached rigidly to the drum shaft. Based upon the preliminary experiments following assumptions were made to avoiding that any experimental point get burn.

Design assumptions

- It was assumed that the torque on the locking plate is utilised for meat separation and it transmitted radically over the perforated drum.
- Assume that 40 psi as a total pressure coming on the drum surface (Robertson and Merritt 1985) and out of that, 50% pressure required for meat-bone separation came due to the drum movement and the remaining 50% pressure came from the tensioned food grade rubber belt on drum.
- Pressure on drum surface due to drum movement = $20 \text{ psi} = 137931 \text{ N/m}^2$
- Drum speed as 20 rpm and Gear ratio as 1:1.55
- Belt-drum contacts = 35% of the drum perimeter (Bykowski and Dutkiewicz 1996)

Design parameters

- Outer diameter of drum (D_{od}) = 0.164 m
- Inner diameter of drum (D_{id}) = Diameter of locking plate = 0.152 m
- Radius of locking plate = 0.076 m
- Perimeter of drum (P_d) = $\pi D_o = 0.515 \text{ m}$
- Effective perimeter of contact (P_c) = $0.35 \times 0.515 = 0.180 \text{ m}$
- Belt width = Effective drum length (L) = 0.150 m
- Contact area = Effective perimeter of contact $\times$ effective length = $0.180 \times 0.150 = 0.027 \text{ m}^2$

Expected force and torque on the drum were calculated using the following equation.

$$\text{Expected force} = \text{Pressure} \times \text{Contact area} \quad (1)$$

$$\text{Expected force} = 137931 \times 0.027 = 3682 \text{ N}$$

$$\text{Torque at the Locking plate (drum drive)} = \text{Force} \times \text{Distance} \quad (2)$$

$$\tau = 3682 \times 0.076 = 279.83 \text{ N-m} \approx 280 \text{ N-m}$$

PLAN

Dimensions are in mm
Scale: Not to scale

ELEVATION SIDE VIEW**Fig. 1** Details of meat-bone separator assembly

The power requirement of the meat-bone separator,

$$P = \frac{2\pi N\tau}{60} \quad (3)$$

$$P = \frac{2\pi \times 20 \times 280}{60} = 586.43 \text{ W}$$

The product thickness increases the initial preload between the drum and pressing medium (Booman et al.

2010) which may lead to overloading during operation. To avoid that factor of safety is considered as 1.2 (Khurmi and Gupta 2005)

Actual power required, $P_a = 1.2 \times 586.43 = 703.72$ W ≈ 1 hp

This shows that, one hp motor (Single phase) with 20 rpm drum speed was suitable for the meat-bone separation. A separate speed reduction gear box (30:1) was used for step down from 1460 rpm to 49 rpm for better meat recovery. The different components such as perfo-

Fig. 2 Isometric view of the developed meat-bone separator 1. Perforated drum 2. Conveyor belt 3. Belt drum 4. Adjustable tension roller 5. Motor 6. Coupling 7. Speed reduction gearbox 8. Spur gear 9. Primary/ drum drive shaft 10. Secondary shaft 11. Chain sprocket mechanism 12. Discharge chute 13. Scraper 14. Locking plate

rated drum (3 mm), Shaft (Primary-31.75 mm Φ , Secondary-25.40 mm Φ), conveyor belt, rollers, bearings and drive system (Coupling-Rating 100, Spur gear, 84 and 56 teeth, Chain drive-12B) were used for fabrication of belt and drum type meat-bone separator. As per the design considerations, the meat-bone separator was fabricated and assembled at central workshop, College of Agricultural Engineering, UAS Raichur, Karnataka, India.

Meat-bone separation process

The low value under-utilised Tilapia fish (*Oreochromis mossambicu*) was procured from the wholesale fish market of Raichur, Karnataka, India. Then the fishes were washed in cold water (0 °C) and kept in the lots of 2.5 kg in deep freezer at -40 °C. Before processing heading and gutting were done on a cutting tray (IS 10763–1983) and the debris and other foreign matter were removed manually. From 2.5 kg lots, weight of the waste (head, tail, guts etc.) and weights of dressed fish were noted. Finally, the dressed fish pieces were washed thoroughly with potable water (0 °C to 5 °C) and kept in lots of 1.8 kg in deep freezer at -40 °C until used.

The dressed fishes from the deep freezer were thawed for one hour and kept in feed tray prior to processing. After thawing, dressed fish were fed manually and scrapping was done continuously with the help of scraper during operation to avoid sticking of waste portions on the outer surface of the drum. Three passes of meat recovery were carried out. After the operation, the minced meat was scrapped

manually from the inner surface of the drum and kept in separate tray. At the end of each pass, the recovered minced meat and waste were weighed separately for yield calculation. The minced meat was packed in polythene pockets, and stored for colour and bone content analysis. After each operation the drum was washed thoroughly, and the conveyor belt was cleaned by hard brush to avoid any contamination.

Performance evaluation of the developed machine

The performance of the machine was evaluated in terms of capacity, yield, yield percentage, bone content, colour and power consumption using 3 mm perforation drum, two belt materials viz. Belt A (35 Shore) and Belt B (65 Shore) at three drum speeds (14, 20 and 24 rpm). The photo/contact type tachometer (Lutron DT-2236) used to measure gear box output speed, drum speed and belt drum speeds.

Capacity (C)

The time taken for passing the total of 1.80 kg dressed fish in each experiment was measured to calculate the capacity of the machine.

Yield

The sum of total minced meat recovered at the end of each pass was considered as the total yield of the machine.

Yield percentage / meat recovery

Yield percentage of the machine was calculated on dressed fish weight basis (Y_d) and on whole fish weight basis (Y_w) using following formulae.

$$Y_d = \frac{\text{Total minced meat recovered}}{\text{Dressed fish weight}} \times 100 \quad (4)$$

$$Y_w = \frac{\text{Total minced meat recovered}}{\text{Whole fish weight}} \times 100 \quad (5)$$

Colour

The spectrophotometer (SS 5100 A, Premier Colorscan) was used to determine the colour of minced meat. The colour of the minced meat was measured using a colour scan spectrophotometer CIELAB scale at 10° observer angle and at D₆₅ illumination.

Bone content

The bone content analysis was carried out using the gravity floatation method (Patashnik et al. 1974). “Kenstar” multiprocessor with blender jar was used for thorough mixing of minced flesh. A sample weighing 100 g was kept in the blender jar, and filled with cold water (5 °C). The processor was run at a lower speed for about 5 min for proper mixing, then the blender jar was kept under the running water at the flow rate of approximately 4.50 L min⁻¹ until the water was essentially free of floating fish muscle fibres. Some of the remaining aggregates of flesh at the bottom were removed manually to make the process of separation of bone, fin and the cartilage easier, followed by, transferring to a petri dish for easy quantitative estimation or counting. For counting, the residue was separated into various components, and the total weight of the bones was weighed using digital balance (± 0.001 g).

Power consumption

The power consumption of the machine was calculated by connecting a set of ammeter, voltmeter and wattmeter in the circuit of the single phase motor. The respective readings of each instrument were recorded during the meat-bone separation for calculating the power requirement (Theraja and Theraja 2003).

Statistical analysis

The data were analyzed statistically using Stat-Soft 6.0 and agricultural statistics procedures (Gomez and Gomez 1976). After analysis, the data were accommodated in the tabular format for interpretation.

Cost economics of meat-bone separator

The total production cost of the machine was calculated by summing the raw material cost, labour charges, electricity and transportation charges was found to be Rs. 55,624/-. The operation cost of the meat-bone separator includes the fixed cost and variable cost. In the fixed cost, annual depreciation, annual interest and taxes were computed by using straight line method (Ojha and Michael 2003). The different parameters of fixed cost such as annual interest, taxes, housing were estimated as 15%, 2% and 1%, respectively of initial investment. The operating cost includes those costs which are a function of the amount used in production process such as of repairs and maintenance (8% of initial investment), electricity charge, lubrication and labour charge.

- i. Labour: Salaries of labour who are directly or indirectly related with production and personnel responsible for

- supervising different operations (Assume 2 labours for 150 working days of 8 working hours per day).
- ii. Utilities: Electric power, oil cost were estimated from specific consumption and unit prices.
- iii. Expected return: The expected return of the machine was estimated based on the basis of hourly operation cost of the meat-bone separator. The expected return was estimated for calculations of pay-back period and B:C ratio (Reddy et al. 2004).

Results and Discussion

Results of developed meat-bone separator

Various machine elements such as prime mover (1 hp motor), sprockets, chain drive, shafts, gears and coupling were designed by following the standard design procedures. The stainless steel drum of 3 mm perforation size was used for evaluation. Regenstien (1986) concluded also the use of 3 to 5 mm hole sizes for better meat separation. The drum and belt of the machine were counter rotating as remarked by Robertson and Merritt (1985); a pair of spur gears was designed and used in the transmission system for changing the direction of rotation of drum and belt. Therefore, one hp motor with 20 rpm drum speed was selected for the meat bone separation with 30:1 speed reduction gear box for maximum meat recovery.

Results of performance evaluation of meat-bone separator

Comparison of theoretical and actual speeds

The actual speeds of the gear box output, perforated drum speed, and the belt drum speed agreed well with the corresponding values obtained in design phase. Speed of the gear box output sprocket was found to be constant throughout the experiment. The theoretical values of the drum speeds of 14, 20 and 24 rpm agreed well to observed values of 13.9, 19.5 and 23.8 rpm respectively for the belt A, and 14.1, 20.1 and 24.2 rpm for the belt B, showing a minimum speed variation with respect to the theoretical speed values.

Capacity of the machine

The capacity of the machine at 14, 20 and 24 rpm drum speed were observed to be 45.59, 52.06 and 68.54 kg h⁻¹, respectively for belt A, whereas for belt B was 49.13, 69.32 and 78.13 kg h⁻¹, respectively. The variation in capacity with change in speed was might be due to the time taken to pass the raw material reduced with increase in speed. The developed meat-bone separator was on par

with the IDRC developed machine whose capacity was varied with 63 to 83 kg h⁻¹ but it was lowered to 32 to 36 kg h⁻¹ upon continuous operation (IDRC 1986). It was also observed that, the capacity of the developed machine did not decrease with the continuous operation as found in machine developed by IDRC.

Yield and percentage yield of the meat-bone separator

The trend of total yield and yield percentage values from the different belt material for three drum speeds are given in Table 1. For belt A (35 Shore), the maximum yield (1.148 kg) was recorded at 14 rpm drum speed, which was 63.78% on dressed weight basis, and 45.92% on whole weight basis. For belt B (65 Shore), the highest yield was 1.312 kg at 20 rpm drum speed which was 72.89% on dressed weight basis and 52.46% on whole fish weight basis. The results obtained were on par with the earlier reports, Sen (2005) concluded that yield of mince as 52 to 72% on dressed weight basis from BARC machine, and similarly Robertson and Merritt (1985) reported 70% minced meat recovery from IDRC machine. The results obtained were significantly more than drum and beam type meat separator (46.4±1.70% on whole carp weight basis) as reported by Booman et al. (2010).

Effect of number of passes on meat colour

In all the experiments, it was found that L* value was highest for the meat obtained during Pass-1 as compared to Pass-2 and Pass-3 (Table 2). It was also found that, L* values of the meat obtained using belt A (35 Shore) was more than that of

Table 2 Mean and Standard deviation of colour values of meat recovered from different passes

Belt	Pass	L*	a*	b*
A	1	55.56±1.5	1.49±0.5	9.58±0.5
	2	54.21±0.7	1.66±0.4	8.94±0.7
	3	52.14±0.6	1.41±0.5	9.32±0.1
B	1	53.57±1.7	1.40±0.6	9.22±0.3
	2	51.07±1.1	1.42±0.5	9.16±0.1
	3	48.14±2.8	1.31±0.1	8.74±0.4

obtained using belt B (65 Shore), this may be due to the increased hardness of the belt which may results in squeezing of skin and other pigments along with flesh. For belt A, L*, a* and b* respectively varied from 52.14 to 55.56, 1.41 to 1.66 and 8.94 to 9.58 for three passes, and for the belt B, they were 48.14 to 53.77, 1.31 to 1.42 and 8.74 to 9.22 for three passes. Similar results were reported by Huang et al. (2004) for Tilapia fish, who found L*, a* and b* values as 52.05±0.29, 2.3±0.52 and 2.89±0.89, respectively.

Bone content

Table 3 summarises the mean weight and standard deviation of the bone fragments recovered from the minced meat samples by gravity floatation method. It was revealed from the results that with increase in the number of passes, the chances of insertion of the bones in minced flesh became more. The highest bone content (3.82 and 3.77 mg/100 g) was observed at third pass for both belt A and B. The maximum bone content in all the experiment was found to be less as compared to previous results of other researchers. Ghadi et al. (1975), Wong et al. (1978) found the more bone content as compared to the results obtained in the present study. Speed variation does not have much significant effect on the bone content in the minced meat as the variation observed is very less with respect to speed.

Table 1 Yield and yield percentage at different belt materials and at different drum speeds

Belt	Drum speed (rpm)	Capacity (kg/h)	Yield (kg)	Y _d (%)	Y _w (%)
A	14	45.59	1.148	63.78	45.92
	20	52.06	1.069	59.39	42.76
	24	68.54	1.066	59.22	42.64
	Mean	55.40	1.094		
	SD		0.05		
B	14	49.13	1.253	69.61	50.12
	20	69.32	1.312	72.89	52.46
	24	78.13	1.269	70.50	50.76
	Mean	65.53	1.278		
	SD		0.03		

% Y_d-Yield percentage based on dressed meat, % Y_w-Yield percentage based on whole meat

Dressed fish weight was 1.8 kg in all above cases/ experiments

Table 3 Mean and Standard deviation of bone content (mg/100 g) for different passes

Belt	Drum speed (rpm)	Pass 1	Pass 2	Pass 3
A	14	1.82±0.2	2.20±0.3	3.82±0.4
	20	1.59±0.1	1.82±0.2	2.33±0.3
	24	1.49±0.2	1.69±0.2	2.03±0.3
B	14	1.80±0.2	2.23±0.2	3.77±0.4
	20	1.53±0.2	1.93±0.1	2.47±0.2
	24	1.47±0.2	1.74±0.2	2.14±0.1

Energy consumption

The power consumed by the machine was almost constant regardless of the variation in drum speed. The mean power requirements for the machine with belt A and B were 755.56 W and 768.89 W, respectively.

Results of cost economics of developed meat-bone separator

The production cost and the operation costs were calculated based upon the standard procedure for meat-bone separator. The total production cost of the machine was found to be Rs. 55,624.00 which was less than the earlier reports of Rs. 2.00 lakh (DARE 2007), CAD 6000 ($\approx$ Rs. 2,70,000/-) (Robertson and Merritt 1985) and CAD 1500 ($\approx$ Rs. 67,500/-) (IDRC 1986) and the annual cost of operation was recorded as Rs. 57,470.00 (Rs. 47.89 per hour or approx. 0.60 Rs./kg). The B-C ratio of the machine was found to be 1.48 and the payback period is 1.08 years (12 months, 29 days).

Conclusion

The fish meat-bone separator was developed based on designed components, and evaluated for its performance. The integration of processing variables, quantitative and qualitative parameters and cost economics of the machine has shown the necessity of adoption of this technique for the benefits of small and medium scale fish processing industry. The maximum yields of 1.148 kg (63.78% on dressed weight basis) was recorded using the belt A at 14 rpm drum speed and that of 1.312 kg (72.89% on dressed weight basis) was obtained for the belt B at 20 rpm drum speed. The increased number of passes achieving more meat recovery resulted in increased chances of insertion of bone fragments into the minced meat, and decreased the colour values of the recovered meat. The power consumption remained constant (755 ± 10 W) for all the experiments. Therefore there is a huge potential of using the meat-bone separator developed for small and medium scale fish processing industries.

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