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Development and Evaluation of an Automatic Feeder Unit for Intensive Fish Farms

Mohamed F. Hany*, El-Sayed G. Khater and Adel H. Bahnasawy****

* Graduate Student of Agric. Eng. Dep., Fac. of Agric., Benha Univ., Egypt

** Professor of Agric. Eng., Fac. of Agric., Benha Univ., Egypt

Corresponding author: alsayed.khater@fagr.bu.edu.eg

Abstract

The main aim of the present study is to develop, fabricate and evaluate an automatic feeder for fish feeding. The effect of different feed pellets sizes (1, 2 and 3 mm), air flow rates (15, 20 and 25 m^3 min^{-1}) and rotational speeds of screw (200, 350, 500, 650 and 800 rpm) were studied. The automatic feeder productivity, efficiency, specific energy consumption and costs were determined. The results indicated that the productivity on the automatic feeder increased from 133.66 to 157.86, 129.15 to 162.15 and 41.12 to 240.73 kg hr^{-1}, with increasing feed pellets size from 1 to 3 mm, air flow rate increased from 15 to 25 m^3 min^{-1} and rotational speed of screw increased from 200 to 800 rpm, respectively. The efficiency of the automatic feeder increased from 61.95 to 77.48, 61.92 to 79.03 and 58.23 to 77.16%, with increasing feed pellets size from 1 to 3 mm, air flow rate increased from 15 to 25 m^3 min^{-1} and rotational speed of screw increased from 200 to 800 rpm, respectively. The specific energy consumption of automatic feeder decreased from 8.93 to 7.25, 10.96 to 5.76 and 10.17 to 6.51 W.hr kg^{-1}, with increasing feed pellets size from 1 to 3 mm, air flow rate increased from 15 to 25 m^3 min^{-1} and rotational speed of screw increased from 2000 to 800 rpm, respectively. The total cost of automatic feeder ranged from 0.05 to 0.29 LE kg^{-1} for all treatments under study.

Keywords: Automatic feeder, Productivity, Efficiency, Energy, Cost

Introduction

In aquaculture systems the cost of feed is the highest operating cost. In an eel fish culture system, the cost of feed accounted for approximately 40% of the total operating cost **(Timmons et al., 1994)**. It was estimated that more than 60% of the feed applied to aquacultural system ends up as particulate matter **(Masser, 1992)**. The decomposition of solids leads to oxygen depletion and produce ammonia–nitrogen and other toxic compounds detrimental to aquatic life, such as hydrogen sulphide. Feeding pattern is a very important aspect to apply feed in an aquaculture system. Hence, feeding rhythms also affect feed conversion rates (FCR) and proximal composition of fish flesh **(Tanveer et al., 2018)**.

Feeding is considered as one of the critical factors in fish growth and production **(Mohd et al., 2020 and Ogunlela and Adebayo, 2016)** and is labour intensive and expensive. In general, the fish growth and feed conversion increases with feeding frequency. In the intensive fish culture systems, fish may be fed as many as five times a day **(Rewatkar et al., 2018)** to attain maximizes growth at optimum temperatures. Most of the fish farmers adopt the manual feeding system, which is dependent on labour availability, farm size, fish species and size of the fishes. The traditional manual feeding system requires more manual labour for cleaning the feeder, refilling with feed, repair and maintenance etc. All these processes involve considerable energy consumption and require more time. Moreover, in larger fish farms, the manual feeding system users are facing difficulty in managing the entire feeding schedule. Hence, there is a need to develop an efficient feeder system to overcome the problems encountered in manual feeding system. Many research findings showed that the automatic fish feeder, an electronic device is efficient in dispensing right quantity of pellets, powders and granules in right time and hence can be an alternative for traditional manual feeding system **(Yeoh et al., 2010, Uddin et al., 2016 and Babu and Mahesh, 2019)**. In general, two basic concepts which are fixed and mobile conceived the automatic fish feeder **(Ojo and Benard, 2018)**. This device fed fish in right time and amount pre-defined by user, and hence avoids the problem of overfeeding **(Ozigbo et al., 2013)**. Moreover, the automatic feeder resulted in more systematic feeding schedule which decreased the labor cost considerably.

The rise of automatic feeders has allowed farmers to increase the number of feedings without increasing the labor required **(Bador et al., 2013)**. This could be due to the fact that feed is not stay in the water for as long, resulting in less physical breakdown before consumption **(Obaldo et al., 20002)**. Feed stability requirements could be reduced if diets are attractive and consumed quickly. This may be relevant to feed management as feeds with lower stability may be formulated with lower-cost ingredients **(Lim and Cuzon, 1994)**. Another advantage of dynamic feed management is the possibility of lowering waste from feed that is fed but not eaten. Overfeeding has also been shown to increase pond pollution and the expense of water quality management **(Kaushik, 2000)**. Most of the time overfeeding is related to the practice of feeding the fish until satiation is reached.

Yeoh el al. (2010) developed an automatic feeder with adjustable parameters. It was developed to fulfil certain objectives and requirements with added advantages such as detachable hopper to accommodate various sizes of hopper according to user's requirement. It was also designed to have adjustable height, speed, and opening angle to accommodate different sizes of fish tanks and ponds. Moreover, it provides a mobile fish feeder with a pneumatic system for safety reasons. The developed feeder used for rearing Tilapia and Catfish. The dimension of that feeder is 0.8 m (length) x 0.5 m (width) x 1.6 m (height). It consists of few components such us hopper, lift, compressor, propeller, dosing valve, and process control panel. The feeder also controlled by a digital timer with a feeding rate is 250 gr/ min. This automatic fish feeder can be implemented in any aquaculture by adjusting to the available technology and required equipment size, but it is not equipped with an alarm system to monitor the feed supply.

Mohapatra *et al.* (2009) developed and tested a demand fish feeder, fabricated with Fiber Reinforced Plastic (FRP) material. The feeder was specifically for carp, and was tested in outdoor culture systems. Demand feeders, controlled by the fish needs, could be bait-rod (pendulum) type or submerged plate-type **(Varadi, 1984)**. **Tadayoshi (2003)** developed an automatic fish feeder which had the capability of sensing uneaten feed. **Noor *et al.* (2012)** designed an automatic fish feeder using PIC microcontroller. The basic components of the feeder are pellet storage, former, stand, DC motor and microcontroller.

One parameter that involves in a feeder is time management controller that act as main part of a feeder. Many industrialists in aqua field and also fish owner seem to have trouble with this timely operation. Traditional method of feeding fish either for fish in pond, cage or even small lake is by use of man power. For the worker, they sometime face difficulties to do the feedings at the same exact time during some unexpected event especially when raining. If the they continue the job, the only result are not just the pellet ending at the bottom of the pond as waste faster or lead water to pollute, but the main critical problem is the unfed fish. This matter will even grow bigger during raining season and will cost a lot of trouble to the industrialist **(Yeoh *et al.*, 2010)**.

Fish feeding is a tedious and time consuming operation, seeking for a tool to save effort and time beside of the uniformity distribution was the main aim of this work is to develop a low cost and locally made automatic fish feeder.

1. Materials and methods

The main experiment of this study was carried out at Agricultural and Bio-Systems Engineering Department, Faculty of Agriculture Moshtohor, Benha University, Egypt to develop, fabricate and evaluate an automatic fish feeder, during the period of June to August, 2024 season..

1.1. Materials

1.1.1. Machine description

The electrically operated machine was designed, fabricated and evaluated. Figs. 1 and 2 show the isometric drawing, the orthographic drawing and the picture of the machine. The components of the feeder include the frame, the feed hoper, screw auger, electrical motor and control unit.

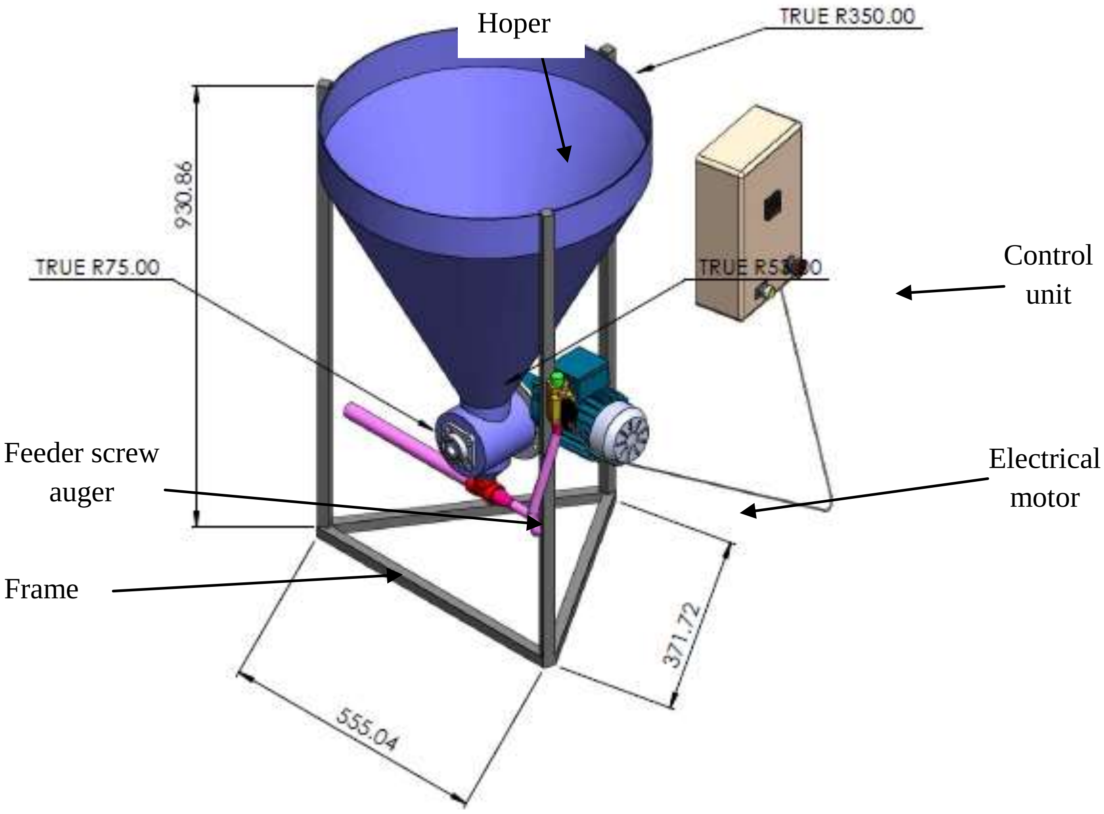
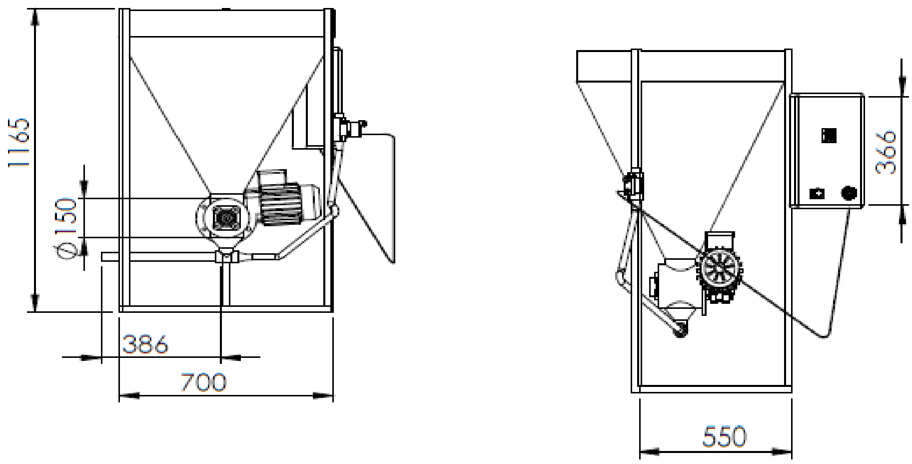


Fig. 1. Schematic diagram of the automatic feeder (dimension in mm).



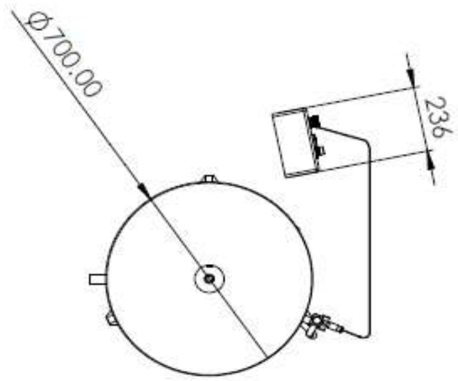


Fig 2. Orthographic drawing of the automatic fish feeder (dimension in mm).

1.1.1.1. The feeder frame

The main frame of the machine was constructed from iron section (30×30×3 mm for wide, high and thickness, respectively). Dimensions of the machine frame are 700 mm long, 700 mm wide and 1165 mm height.

1.1.1.2. Feed hoper

The feed hopper is made of stainless steel (3mm thickness) and it is a cylindrical shape. The top diameter is 70 cm, the bottom diameter is 15 cm and the height of feeder hoper is 70 cm. The capacity of feed hopper was 90 L.

1.1.1.3. Screw auger

Fig. 3 shows the schematic diagram of the screw auger. The screw auger is made from local material and used to handle the product within the plant. Screw auger consists of a screw wraps around shaft or rotation axis -by- fixed pitch. The spins inside bearings column installed on the base of loading and spin auger inside the circular stream called auger basin. Form sacrificed actual parts of the augers.

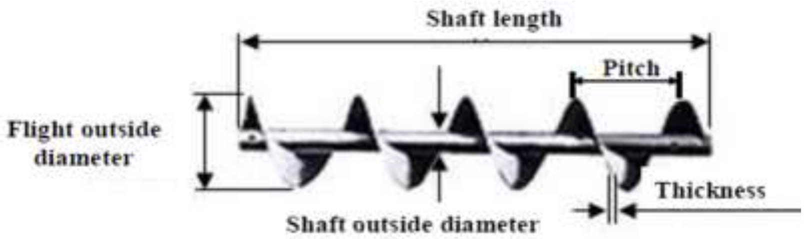


Fig. 3. Schematic diagram of screw auger.

1.1.1.4. Electrical motor

The feeder is driven by single phase electric motor (Model GAMAK –Power 0.37 kW 220V 50Hz, Turkey). The power was transmitted to main shaft of the screw auger of feeder, the speed of motor is 1400 rpm.

1.1.1.5. Control unit

Control unit was used to regulate the speed of motor from 1400 rpm to the required speeds to operate the auger screw. Also, control unit used to control operation time.

1.2. Methods

The developed automatic fish feeder was evaluated by studying the effect of feed pellets size, air flow rate and rotational speed of screw on the evaluation parameters.

1.2.1. Experimental design

The treatments were arranged in a split-split plot design with three replications. The treatments include: three feed pellets sizes are 1, 2 and 3 mm, three air flow rates are 10, 15 and 15 $m^3\ min^{-1}$ and five rotational speed of screw are 180, 360, 540, 720 and 900 rpm with operating time of 5 min.

1.2.2. Measurements

1.2.2.1. Automatic feeder productivity

The automatic feeder productivity (kg) was determine as the amount of the fish feed during operation time.

1.2.2.2. Automatic feeder efficiency

Automatic feeder efficiency was estimated using the following equation:

$$\eta = \frac{Pr_{actual}}{Pr_{theoretical}} \times 100 \qquad (1)$$

Where:

η is the automatic feeder efficiency, %

Pr_{actual} is the actual productivity, kg

$Pr_{theoretical}$ is the theoretical productivity, kg

Theoretical productivity of automatic feeder was determined from equation according to **Khater *et al.* (2021)**:

$$P_t = \frac{\pi}{4} PN\left(D_1^2 - D_2^2\right)\rho Km \qquad (2)$$

Where:

Pr_t is the theoretical productivity, kg min^{-1}

P is the pitch length, cm

N is the rotational speed of screw, rpm

D^2_1 is the flight outside diameter, cm

D^2_2 is the shaft outside diameter, cm

ρ is the bulk density of fish feeds with different sizes, kg cm^{-3}

K is the loading factor

m is the constant depending on the inclination angle

2.2.2.3. Power and energy requirement for automatic fish feeder

The power requirement (kW) was estimated by using the clamp meter to measure the line current strength (I) and the potential difference value (V).

The total electric power requirement under machine working load (P) was calculated according to **Kurt (1979)** by the following equation:

$$P = \frac{I \times V \times \cos\theta}{1000} \qquad (3)$$

Where:

P is the power requirement to automatic feeder, kW

I is the line current strength, Amperes.

V is the potential difference, Voltage.

Cos θ is the power factor, equal 0.8.

The specific energy consumption (SEC) in kW kg^{-1} was calculated using the following equation:

$$SEC = \frac{P}{Pr_{actual}} \qquad (4)$$

Where:

SEC is the specific energy consumption, W kg^{-1}

1.3. Total Costs

The costs of operating the feeder were calculated according to **Khater et al. (2021)**. Table (1) shows inputs of cost components.

Table 1. Cost inputs.

Items	Cost, LE
Price of equipment, LE.	25000
Motor, kW	0.37
Life expected, year	5
Taxes, %	3
Repair, %	10
Interest, %	10
Labors, LE h^{-1}	30

Results and discussions

3.1. Automatic feeder productivity

Table 1 shows the effect of the different feed pellets sizes (1, 2 and 3 mm), air flow rates (15, 20 and 25 m^3 min^{-1}) and rotational speeds of screw (200, 350, 500, 650 and 800 rpm) on the productivity of the automatic feeder. The results indicate that, the productivity of the automatic feeder increases with increasing air flow rate, feed pellets size, and rotational speed of screw. It could be seen that, the productivity of automatic feeder was increased from 133.66 to 157.86 (by 18.11%) kg hr^{-1}, when the feed pellets size increased from 1 to 3 mm, respectively. It also indicates that, the productivity of automatic feeder was increased from 129.15 to 162.15 (by 25.55%) kg hr^{-1}, when the air flow rate increased from 15 to 25 m^3 min^{-1}, respectively. While the automatic feeder productivity increased from 41.12 to 240.73 (by 82.92%) kg hr^{-1}, when the rotational speed of screw increased from 200 to 800 rpm, respectively. These results are in agreement with those obtained by **Khater *et al.* (2021)** whose found the the productivity of the automatic feeder increased with increasing feed pellets size, air flow rate, and rotational speed of screw.

Table 1. Productivity of automatic feeder at different feed pellets sizes, air flow rates and rotational speeds of screw.

Feed Pellets Size, mm	Flow rate, m^3 m^{-1}	Rotational speed of Screw, rpm					Mean
		200	350	500	650	800	
		Automatic Feeder Productivity, kg hr^{-1}					
1	15	25.8	61.08	134.04	170.64	196.8	**117.67**
	20	36.24	73.56	140.28	192.84	219.96	**132.58**
	25	51.12	91.68	158.76	207.48	244.56	**150.72**
	Mean	**37.72**	**75.44**	**144.36**	**190.32**	**220.44**	
2	15	26.76	76.92	147.12	177.48	216.24	**128.90**

	20	36.96	89.16	157.2	194.88	242.16	**144.07**
	25	52.44	105.84	173.64	209.64	262.44	**160.80**
	Mean	**38.72**	**90.64**	**159.32**	**194**	**240.28**	
3	15	32.28	93.72	147.24	189.48	241.68	**140.88**
	20	44.64	106.2	160.32	213.6	264.12	**157.78**
	25	63.84	127.32	171.48	233.4	278.64	**174.94**
	Mean	**46.92**	**109.08**	**159.68**	**212.16**	**261.48**	
Mean of size (A)		133.66		144.59		157.86	
Mean of flow rate (B)		129.15		144.81		162.15	
Mean of speed (C)		41.12	91.72	154.45	198.83	240.73	

It could be noticed that, at the average value of flow rate, when the rotational speed of screw changed from 200 to 800 rpm, the productivity of the feeder increased from 37.72 to 220.44, 38.72 to 240.28 and 46.92 to 261.48kg hr^{-1} for 1, 2 and 3 mm feed pellets sizes, respectively. As the feed pellets size increased from 1 to 3 mm, the productivity of the feeder increased from 37.72 to 46.92, 75.44 to 109.08, 144.36 to 159.68, 190.32 to 212.16 and 220.44 to 261.48 kg hr^{-1} at 200, 250, 500, 650 and 800 rpm rotational speed of screw, respectively (fig.4).

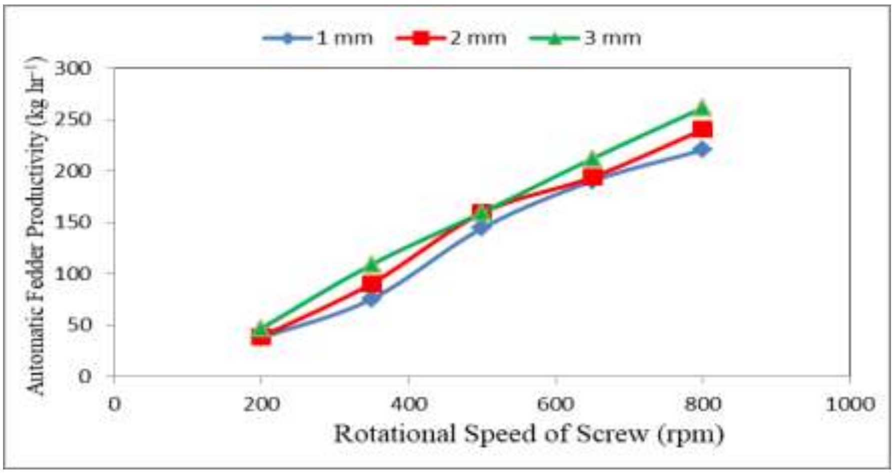


Fig. 4. Effect of different rotational speeds of screw and feed pellet sizes on the productivity of the automatic feeder at the average value of flow rate.

The results indicate that, at the average value of rotational speeds of screw, the productivity of the feeder increases with increasing the feed pellets size and air flow rate. It increased from 117.67 to 150.72, 128.90 to 160.80 and 140.88 to 174.94 kg hr^{-1} for 1, 2 and 3 mm feed pellets size, respectively. However, when the air flow rate changed from 15 to 25 m^3 min^{-1}, the productivity of the feeder increased from 117.62 to 140.88, 132.58 to 157.78 and 150.72 to 174.94 kg hr^{-1} for 15, 20 and 25 m^3 min^{-1} air flow rate, respectively (fig. 5).

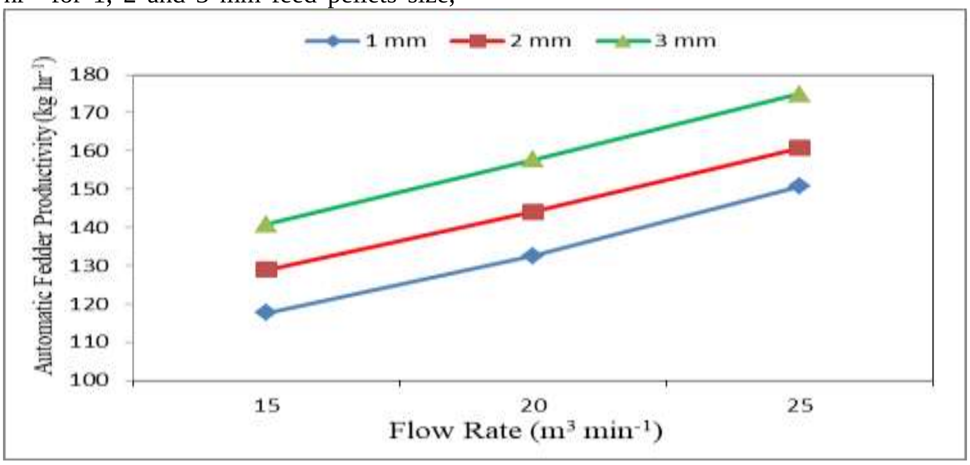


Fig. 5. Effect of the different feed pellet sizes and air flow rates on the productivity of the feeder at the average value of rotational speeds of screw.

The results also indicate that, at the average value of pellet sizes, the productivity of the feeder increased from 28.28 to 218.24, 39.28 to 242.08 and 55.80 to 261.88 kg hr^{-1} at 15, 20 and 25 m^3 min^{-1} air flow rate, respectively. On the other hand, as air flow rate increased from 15 to 25 m^3 min^{-1}, the productivity of the feeder increased from 28.28 to 55.80, 77.24 to 108.28, 142.80 to 167.96, 179.20 to 216.84 and 218.24 to 261.88 kg hr^{-1} at 200, 350, 500, 650 and 850 rpm rotational speed of screw, respectively (fig 6).

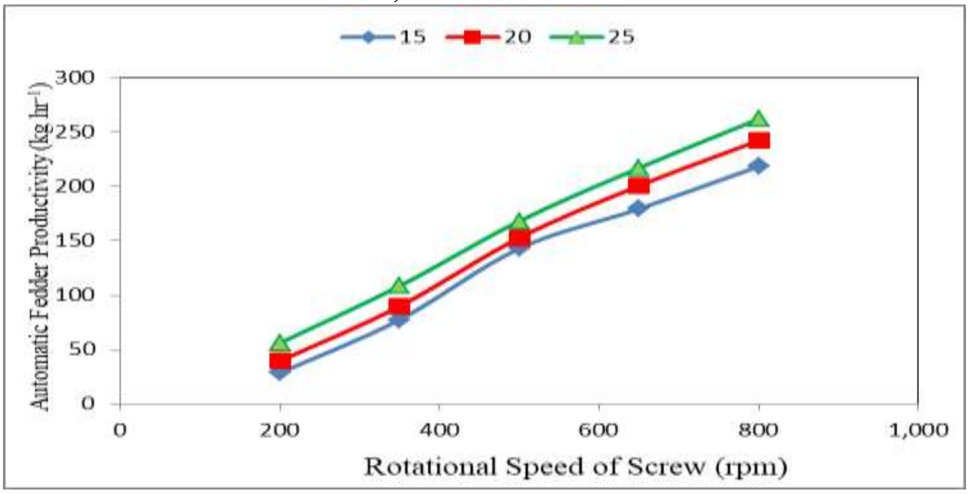


Fig. 6. Effect of the different rotational speeds of screw and flow rates on the productivity of the feeder at the average value of pellet sizes.

Multiple regression analysis was carried out to obtain a relationship between the productivity of the automatic feeder as dependent variable with respect to feed pellets size, air flow rate and rotational speed of screw as independent variables. The best fit for this relationship is presented in the following equation:-

$$Pr_{actual} = -113.36 + 11.59 PS + 3.301 FR + 0.34 RS$$

$$R^2 = 0.98 \qquad (5)$$

Where:

Pr_{actual} is the productivity of automatic feeder, kg hr^{-1}

PS is the feed pellets size, mm

FR is the air flow rate, m^3 min^{-1}

RS is the rotational speed of screw, rpm

3.2. Automatic feeder efficiency

Table 2 shows the effect of the different feed pellets sizes (1, 2 and 3 mm), air flow rates (15, 20 and 25 m^3 min^{-1}) and rotational speeds of screw (200, 350, 500, 650 and 800 rpm) on the efficiency of the automatic feeder. The results indicate that, the efficiency of the automatic feeder increases with increasing air flow rate, feed pellets size, and rotational speed of screw. It could be seen that, the efficiency of automatic feeder was increased from 61.95 to 77.48 (by 25.07%) %, when the feed pellets size increased from 1 to 3 mm, respectively. It also indicates that, the efficiency of automatic feeder was increased from 61.92 to 79.03 (by 27.63%) %, when the air flow rate increased from 15 to 25 m^3 min^{-1}, respectively. However, while the automatic feeder efficiency increased from 58.23 to 77.16 (by 35.56%) %, when the rotational speed of screw increased from 200 to 800 rpm, respectively. These results are in agreement with those obtained by **El-Shal *et al.* (2021)**.

Table 2. Efficiency of automatic feeder at different feed pellets sizes, air flow rates and rotational speeds of screw.

Feed Pellets Size, mm	Flow rate, m^3 m^{-1}	Rotational speed of Screw, rpm					Mean
		200	350	500	650	800	
		Efficiency of automatic feeder, %					
1	15	38.91	48.15	61.37	58.07	60.43	**53.39**
	20	55.98	57.01	64.66	67.13	68.91	**62.74**
	25	62.54	65.87	71.31	73.73	75.2	**69.73**
	Mean	**52.48**	**57.01**	**65.78**	**66.31**	**68.18**	
2	15	39.96	58.29	75.21	70.66	71.56	**63.14**
	20	55.17	67.45	78.83	79.87	78.93	**72.05**
	25	78.82	80.38	81.39	86.47	84.39	**82.29**

	Mean	**57.98**	**68.71**	**78.48**	**79.00**	**78.29**	
3	15	49.30	67.73	76.39	75.10	77.69	**69.24**
	20	65.75	71.59	81.31	85.04	86.93	**78.12**
	25	77.65	81.03	86.88	89.39	90.37	**85.06**
	Mean	**64.23**	**73.45**	**81.53**	**83.18**	**85.00**	
Mean of size (A)		61.95		72.49		77.48	
Mean of flow rate (B)		61.92		70.97		79.03	
Mean of speed (C)		58.23	66.39	75.26	76.16	77.16	

It could be noticed that, at the average value of flow rate, when the rotational speed of screw changed from 200 to 800 rpm, the efficiency of the feeder increased from 52.48 to 68.18, 57.98 to 78.29 and 64.23 to 85.00% at 1, 2 and 3 mm feed pellets sizes, respectively. The results also indicate that the efficiency of the feeder from 52.48 to 64.23, 57.01 to 73.45, 65.78 to 81.53, 66.31 to 83.18 and 68.18 to 85.00% at 200, 250, 500, 650 and 800 rpm rotational speed of screw, respectively when the feed pellets size increased from 1 to 3 mm as shown in fig.7.

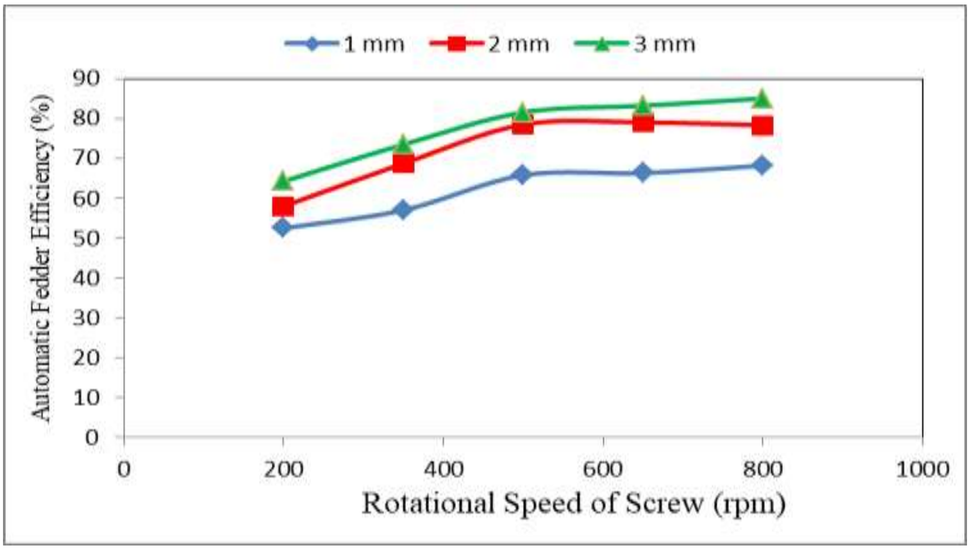


Fig. 7. Effect of different rotational speeds of screw and feed pellet sizes on the efficiency of the automatic feeder at the average value of flow rate.

The results indicate that, at the average value of rotational speeds of screw, the efficiency of the feeder increases with increasing the feed pellets size and air flow rate. It increased from 53.39 to 69.73, 63.14 to 82.29 and 69.24% at 1, 2 and 3 mm feed pellets size, respectively, when the air flow rate increased from 15 to 25 m^3 min^{-1}. The results also indicate that the efficiency of the feeder increased from 53.39 to 69.24, 62.74 to 78.12 and 69.73 to 85.06% for 15, 20 and 25 m^3 min^{-1} air flow rate, respectively, when the feed pellets size increased from 1 to 3 mm as shown in fig. 8.

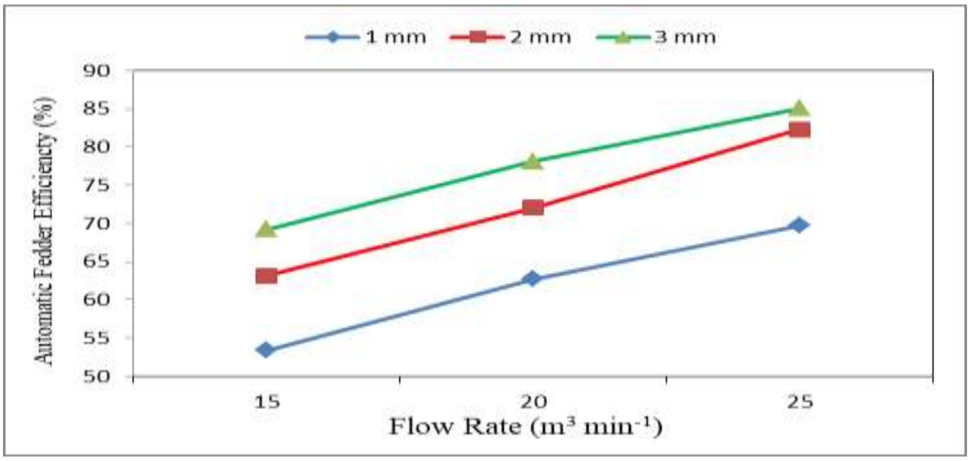


Fig. 8. Effect of the different feed pellet sizes and air flow rates on the efficiency of the feeder at the average value of rotational speeds of screw.

The results also indicate that, at the average value of pellet sizes. The efficiency of the feeder increased from 42.72 to 69.89, 58.97 to 78.89 and 73.00 to 83.32% at 15, 20 and 25 m^3 min^{-1} air flow rate, respectively, when the rotational speed of screw increased from 200 to 800 rpm. The results also indicate that the efficiency of the feeder increased from 42.72 to 73.00, 58.06 to 75.76, 66.99 to 79.86, 67.94 to 83.20 and 69.89 to 83.32% at 200, 350, 500, 650 and 850 rpm rotational speed of screw, respectively, when the air flow rate increased from 15 to 25 m^3 min^{-1}as shown in fig 9.

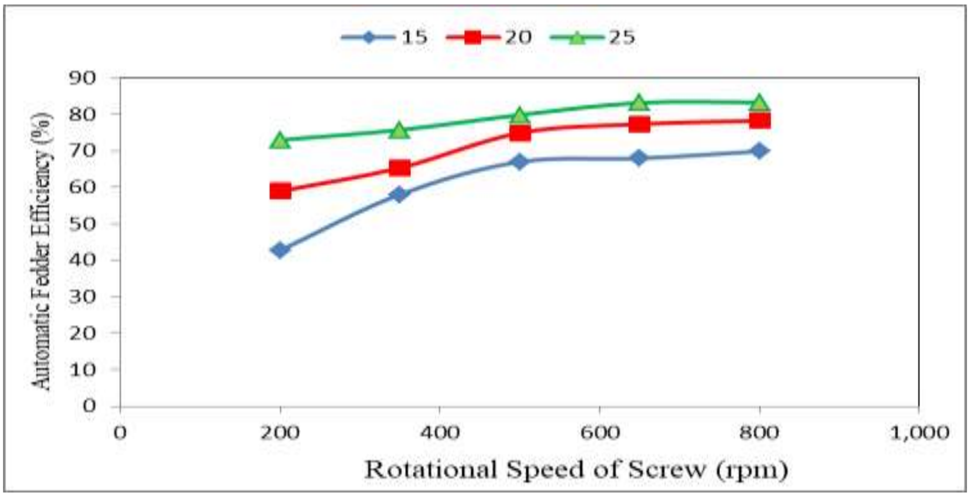


Fig. 9. Effect of the different rotational speeds of screw and flow rates on the efficiency of the feeder at the average value of pellet sizes.

Multiple regression analysis was carried out to obtain a relationship between the automatic feeder efficiency as dependent variable with respect to feed pellets size, air flow rate and rotational speed of screw as independent variables. The best fit for this relationship is presented in the following equation:-

$$\eta = 5.63 + 7.22PS + 1.71FR + 0.03RS$$

$$R^2 = 0.88 \qquad (6)$$

3.3. Specific energy consumption

Table 3 shows the effect of the different feed pellets sizes (1, 2 and 3 mm), air flow rates (15, 20 and 25 m^3 min^{-1}) and rotational speeds of screw (200, 350, 500, 650 and 800 rpm) on the specific energy consumption of automatic feeder. The results indicate that, the specific energy consumption of automatic feeder decreases with increasing air flow rate, feed pellets size, and rotational speed of screw. It could be seen that, the specific energy consumption of automatic feeder was decreased from 8.93 to 7.25 (by 18.81%) W.hr kg^{-1}, when the feed pellets size increased from 1 to 3 mm, respectively. It also indicates that, the specific energy consumption of automatic feeder was decreased from 10.96 to 5.76 (by 47.45%) W.hr kg^{-1}, when the air flow rate increased from 15 to 25 m^3 min^{-1}, respectively. While the specific energy consumption of automatic feeder decreased from 10.17 to 6.51 (by 35.99%) W.hr kg^{-1}, when the rotational speed of screw increased from 200 to 800 rpm, respectively. These results are in agreement with those obtained by **El-Shal *et al.* (2021)**.

Table (3): Specific energy consumption of automatic feeder at different feed pellets sizes, air flow rates and rotational speeds of screw.

Feed Pellets Size, mm	Flow rate, m^3 min^{-1}	Rotational speed of Screw, rpm					Mean
		200	350	500	650	800	
		Specific Energy Consumption, W h kg^{-1}					
1	15	14.17	13.04	11.87	10.53	9.55	**11.83**
	20	10.65	9.87	8.54	8.01	7.16	**8.85**
	25	7.59	6.85	5.72	5.42	5.03	**6.12**
	Mean	**10.80**	**9.92**	**8.71**	**7.99**	**7.25**	
2	15	13.56	12.81	10.69	9.91	9.04	**11.20**
	20	10.03	8.91	8.03	7.11	6.88	**8.19**
	25	8.66	7.43	5.17	5.09	4.47	**6.16**

	Mean	**10.75**	**9.72**	**7.96**	**7.37**	**6.80**	
3	15	11.41	11.77	9.33	8.75	7.92	**9.84**
	20	8.55	8.03	6.63	6.11	5.3	**6.92**
	25	6.92	6.22	4.51	4.16	3.21	**5.00**
	Mean	**8.96**	**8.67**	**6.82**	**6.34**	**5.48**	
Mean of size (A)	8.93			8.52		7.25	
Mean of time (B)	10.96			7.99		5.76	
Mean of speed (C)	10.17		9.44	7.83	7.23	6.51	

It could be noticed that, at the average value of flow rate, when the rotational speed of screw changed from 200 to 800 rpm, tends to increase the specific energy consumption of automatic feeder decreased from 10.80 to 7.25, 10.75 to 6.80 and 8.96 to 5.48 W.hr kg^{-1} at 1, 2 and 3 mm feed pellets sizes, respectively. The results also indicate that the specific energy consumption of automatic feeder decreased from 10.80 to 8.96, 9.92 to 8.67, 8.71 to 6.82, 7.99 to 6.34 and 7.25 to 5.48 W.hr kg^{-1} at 200, 250, 500, 650 and 800 rpm rotational speed of screw, respectively when the feed pellets size increased from 1 to 3 mm as shown in fig.10.

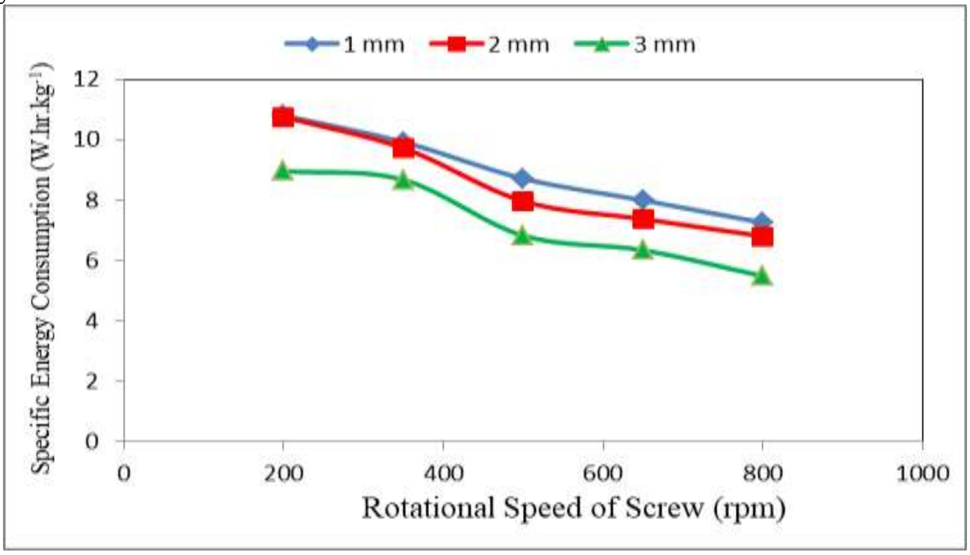


Fig. 10. Effect of different rotational speeds of screw and feed pellet sizes on the specific energy consumption of the automatic feeder at the average value of flow rate.

The results indicate that, at the average value of rotational speeds of screw, the specific energy consumption of the feeder decreases with increasing the feed pellets size and air flow rate. It decreased from 11.83 to 6.12, 11.20 to 6.16 and 9.84 to 5.00 W.hr kg^{-1} at 1, 2 and 3 mm feed pellets size, respectively, when the air flow rate increased from 15 to 25 m^3 min^{-1}. The results also indicate that the specific energy consumption of the feeder decreased from 11.83 to 9.84, 8.85 to 6.92 and 6.12 to 5.00 W.hr kg^{-1} for 15, 20 and 25 m^3 min^{-1} air flow rate, respectively, when the feed pellets size increased from 1 to 3 mm as shown in fig. 11.

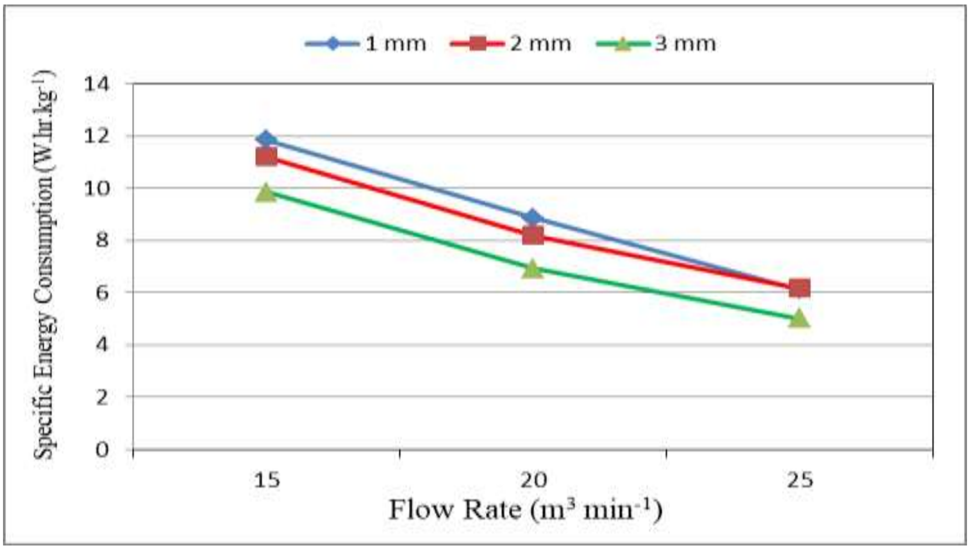


Fig. 11. Effect of the different feed pellet sizes and air flow rates on the specific energy consumption of automatic feeder at the average value of rotational speeds of screw.

The results also indicate that, at the average value of pellet sizes. The specific energy consumption of automatic feeder decreased from 13.54 to 8.84, 9.74 to 6.45 and 7.72 to 4.24 W.hr kg^{-1} at 15, 20 and 25 m^3 min^{-1} air flow rate, respectively, when the rotational speed of screw increased from 200 to 800 rpm. The results also indicate that the specific energy consumption of automatic feeder decreased from 13.05 to 7.72, 12.54 to 6.83, 10.63 to 5.13, 9.73 to 4.89 and 8.84 to 4.24 W.hr kg^{-1} at 200, 350, 500, 650 and 850 rpm rotational speed of screw, respectively, when the air flow rate increased from 15 to 25 m^3 min^{-1}as shown in fig 12.

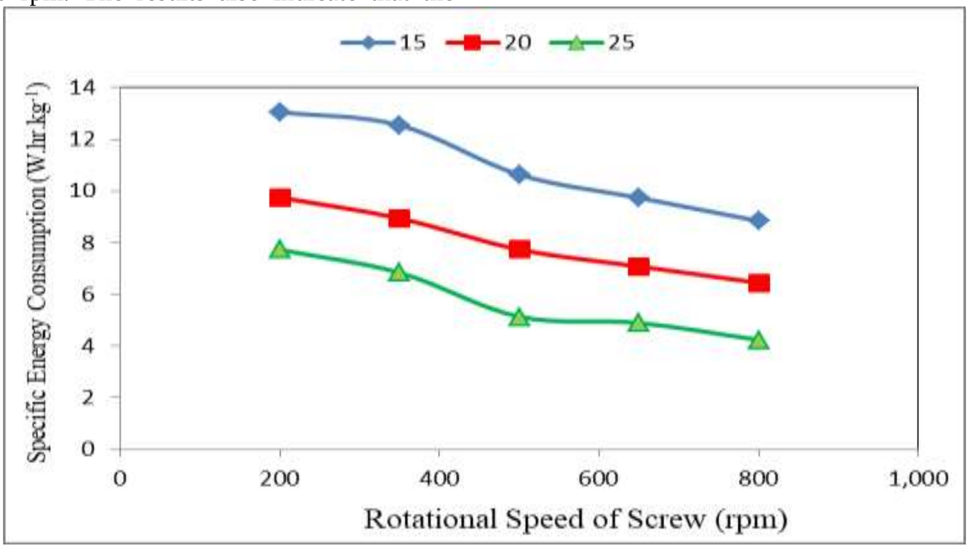


Fig. 12. Effect of the different rotational speeds of screw and flow rates on the specific energy consumption of automatic feeder at the average value of pellet sizes.

Multiple regression analysis was carried out to obtain a relationship between the specific energy consumption of automatic feeder as dependent variable with respect to feed pellets size, air flow rate and rotational speed of screw as independent variables. The best fit for this relationship is presented in the following equation:-

$$SEC = 23.46 - 0.80\,PS - 0.52\,FR - 0.007\,RS$$

$$R^2 = 0.92 \qquad (7)$$

3.3. Total costs of automatic feeder

Table 3 shows the effect of the different feed pellets sizes (1, 2 and 3 mm), air flow rates (15, 20 and 25 m^3 min^{-1}) and rotational speeds of screw (200, 350, 500, 650 and 800 rpm) on the total cost of automatic feeder. The results indicate that, the total cost of automatic feeder decreases with increasing air flow rate, feed pellets size, and rotational speed of screw. It could be seen that, the total cost of automatic feeder was decreased from 0.13 to 0.10 (by 23.08%) LE kg^{-1}, when the feed pellets size increased from 1 to 3 mm, respectively. It also indicates that, the total cost of automatic feeder was decreased from 0.14 to 0.09 (by 35.71%) LE kg^{-1}, when the air flow rate increased from 15 to 25 m^3 min^{-1}, respectively. While the total cost of automatic feeder decreased from 0.29 to 0.05 (by 82.76%) LE kg^{-1}, when the rotational speed of screw increased from 200 to 800 rpm, respectively. These results are in agreement with those obtained by **El-Shal *et al.* (2021)**.

Table 4. Total costs of automatic feeder at different feed pellets sizes, air flow rate and rotational speeds of screw.

Feed Pellets Size, mm	Flow rate, m^3 min^{-1}	Rotational speed of Screw, rpm					Mean
		200	350	500	650	800	
		Total cost of automatic feeder, LE kg^{-1}					
1	15	0.42	0.18	0.08	0.06	0.06	**0.16**
	20	0.3	0.15	0.08	0.06	0.05	**0.13**
	25	0.21	0.12	0.07	0.05	0.04	**0.10**
	Mean	**0.31**	**0.15**	**0.08**	**0.06**	**0.05**	
2	15	0.41	0.14	0.07	0.06	0.05	**0.15**
	20	0.3	0.12	0.07	0.06	0.05	**0.12**
	25	0.21	0.1	0.06	0.05	0.04	**0.09**
	Mean	**0.31**	**0.12**	**0.07**	**0.06**	**0.05**	
3	15	0.34	0.12	0.07	0.06	0.05	**0.13**
	20	0.25	0.1	0.07	0.05	0.04	**0.10**
	25	0.17	0.09	0.06	0.05	0.04	**0.08**
	Mean	**0.25**	**0.10**	**0.07**	**0.05**	**0.04**	
Mean of size (A)		0.13		0.12		0.10	
Mean of time (B)		0.14		0.12		0.09	
Mean of speed (C)		0.29	0.12	0.07	0.06	0.05	

It could be noticed that, at 20 m^3 min^{-1} flow rate, the increasing of rotational speed of screw from 200 to 800 rpm resulted in a decrease of total cost of automatic feeder from 0.31 to 0.05, 0.31 to 0.05 and 0.25 to 0.04 LE kg^{-1} at 1, 2 and 3 mm feed pellets sizes, respectively. The results also indicate that, when the feed pellets size increased from 1 to 3 mm, the total cost of automatic feeder decreased from 0.31 to 0.25, 0.15 to 0.10, 0.08 to 0.07, 0.06 to 0.05 and 0.05 to 0.04 LE kg^{-1} at 200, 250, 500, 650 and 800 rpm rotational speed of screw, respectively (fig.13).

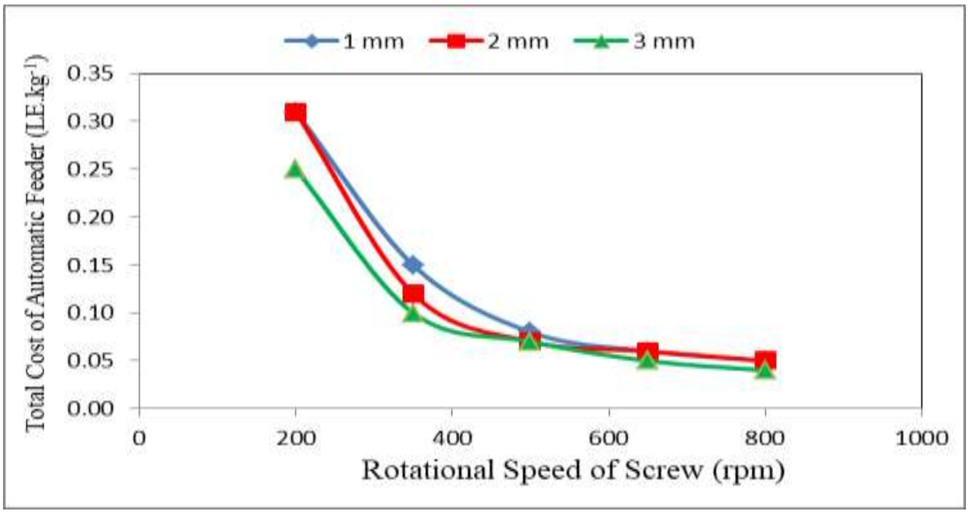


Fig. 13. Effect of different rotational speeds of screw and feed pellet sizes on the total cost of the automatic feeder at 20 m^3 min^{-1} flow rate.

The results indicate that, at the average value of rotational speeds of screw, the total cost of the feeder decreases with increasing the feed pellets size and air flow rate. It decreased from 0.16 to 0.10, 0.15 to 0.09 and 0.13 to 0.08 LE kg^{-1} at 1, 2 and 3 mm feed pellets size, respectively, when the air flow rate increased from 15 to 25 m^3 min^{-1}. The results also indicate that the total cost of the feeder decreased from 0.16 to 0.13, 0.13 to 0.10 and 0.10 to 0.08 LE kg^{-1} for 15, 20 and 25 m^3 min^{-1} air flow rate, respectively, when the feed pellets size increased from 1 to 3 mm as shown in fig. 14.

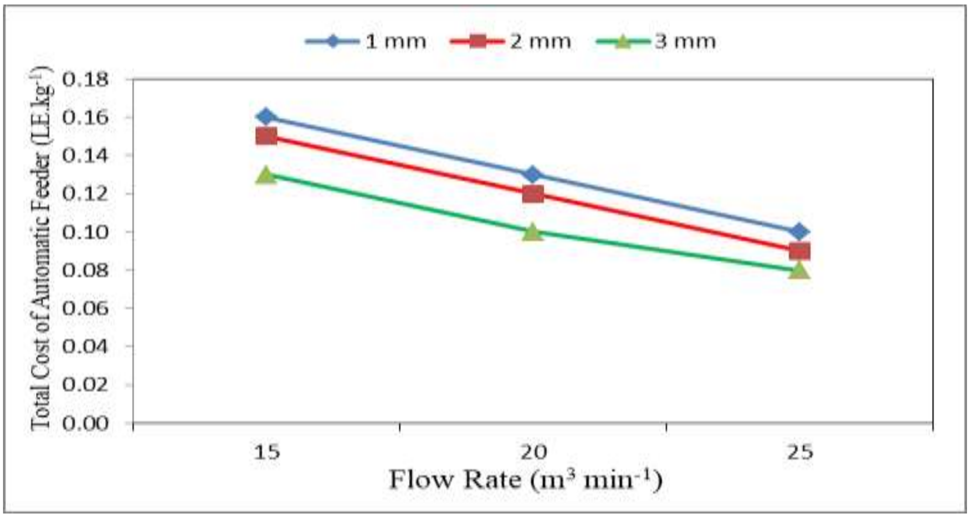


Fig. 14. Effect of the different feed pellet sizes and air flow rates on the total cost of automatic feeder at the average value of rotational speeds of screw.

The results also indicate that, at the average value of pellet sizes. The total cost of automatic feeder decreased from 0.39 to 0.05, 0.28 to 0.05 and 0.20 to 0.04 LE kg^{-1} at 15, 20 and 25 m^3 min^{-1} air flow rate, respectively, when the rotational speed of screw increased from 200 to 800 rpm. The results also indicate that the total cost of automatic feeder decreased from 0.39 to 0.20, 0.15 to 0.10, 0.07 to 0.06, 0.06 to 0.05 and 0.05 to 0.04 LE kg^{-1} at 200, 350, 500, 650 and 850 rpm rotational speed of screw, respectively, when the air flow rate increased from 15 to 25 m^3 min^{-1}as shown in fig 15.

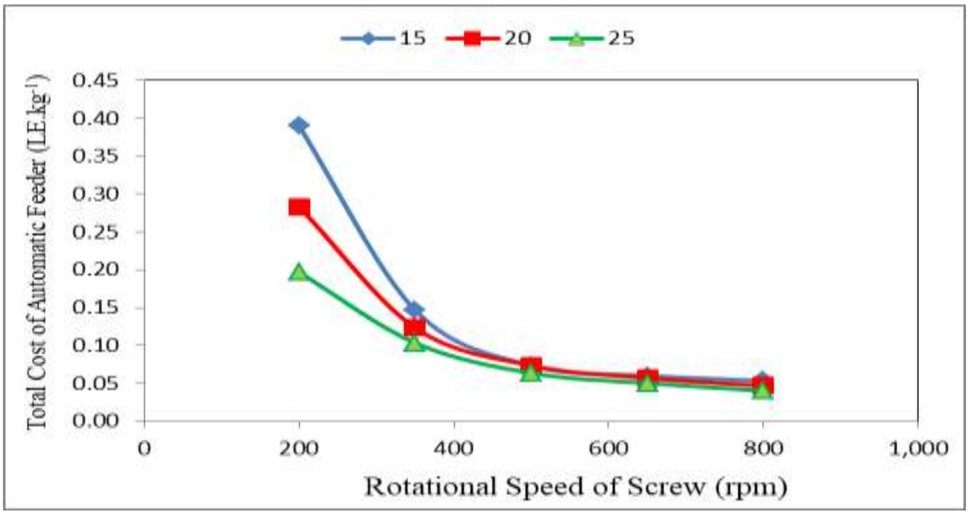


Fig. 15. Effect of the different rotational speeds of screw and flow rates on the specific energy consumption of automatic feeder at the average value of pellet sizes.

Multiple regression analysis was carried out to obtain a relationship between the total costs of automatic feeder as dependent variable with respect to feed pellets size, air flow rate and rotational speed of screw as independent variables. The best fit for this relationship is presented in the following equation:-

$$TC = 0.44 - 0.013PS - 0.005FR - 37 \times 10^{-5} RS$$

$$R^2 = 0.86 \qquad (8)$$

Where:

TC is the total cost of automatic feeder, LE kg^{-1}

Conclusion

The experiment was carried out to study is to develop, fabricate and evaluate an automatic feeder for fish feeding. To achieve that study the effect of different feed pellets sizes (1, 2 and 3 mm), air flow rates (15, 20 and 25 m^3 min^{-1}) and rotational speeds of screw (200, 350, 500, 650 and 800 rpm) on the automatic feeder productivity, efficiency, specific energy consumption and costs. The obtained results can be summarized as follows:

- The productivity of the automatic feeder increased from 133.66 to 157.86 kg hr^{-1}, when the feed pellets size increased from 1 to 3 mm, respectively. It increased from 129.15 to 162.15 kg hr^{-1}, when the air flow rate increased from 15 to 25 m^3 min^{-1}. While, it increased from 41.12 to 240.73 kg hr^{-1}, when the rotational speed of screw increased from 200 to 800 rpm.

- The efficiency of the automatic feeder increased from 61.95 to 77.48%, when the feed pellets size increased from 1 to 3 mm, respectively. It increased from 61.92 to 79.03%, when the air flow rate increased from 15 to 25 m^3 min^{-1}. While, it increased from 58.23 to 77.16%, when the rotational speed of screw increased from 200 to 800 rpm.
- The specific energy consumption of automatic feeder decreased from 8.93 to 7.25 W.hr kg^{-1}, when the feed pellets size increased from 1 to 3 mm, respectively. It also indicates that, the specific energy consumption of automatic feeder was decreased from 10.96 to 5.76 W.hr kg^{-1}, when the air flow rate increased from 15 to 25 m^3 min^{-1}. While the specific energy consumption of automatic feeder decreased from 10.17 to 6.51W.hr kg^{-1}, when the rotational speed of screw increased from 200 to 800 rpm.
- The total cost of automatic feeder decreased from 0.13 to 0.10 LE kg^{-1}, when the feed pellets size increased from 1 to 3 mm, respectively. It decreased from 0.14 to 0.09 LE kg^{-1}, when the air flow rate increased from 15 to 25 m^3 min^{-1}. While, it decreased from 0.29 to 0.05 LE kg^{-1}, when the rotational speed of screw increased from 200 to 800 rpm.

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تطوير وتقييم وحدة تغذية اتوماتيكية للمزارع السمكية المكثفة

محمد فتحى هانى*، السيد جمعه خاطر، عادل حامد بهنساوى****

*طالب دراسات عليا – كلية الزراعة بمشتهر – جامعة بنها

**استاذ الهندسة الزراعية – كلية الزراعة بمشتهر – جامعة بنها

تهدف هذه الدراسة الى تصميم وتصنيع وتقييم غذاية اعلاف اتوماتيكية. تم دراسة تأثير كلا من ثلاث مقاسات لحبيبات العلف (1 – 2 – 3 مم) وثلاثة معدل سريان الهواء (15 – 20 – 25 م^3/دقيقة) وخمسة سرعات دورانية (200 – 350 – 500 – 650 – 800 لفة/دقيقة) على انتاجية وكفاءة الغذاية الاتوماتيكية والاستهلاك النوعى للطاقة وتكاليف تشغيلها. وكانت اهم النتائج المتحصل عليها كما يلى:–

- زادت انتاجية غذاية الاسماك الاتوماتيكية من 133.66 الى 157.86 ومن 129.15 الى 162.15 ومن 41.12 الى 240.73 طن لكل ساعة بزيادة مقاس حبيبات الاعلاف من 1 إلى 3 مم وزيادة معدل سريان الهواء من 15 إلى 25 م^3/دقيقة وزيادة سرعة الدورانية من 200 إلى 800 لفة كل دقيقة، على الترتيب.
- زادت كفاءة غذاية الاسماك الاتوماتيكية من61.95 الى 77.48 ومن 61.92 الى 79.03 ومن 58.23 الى 77.16 % بزيادة مقاس حبيبات الاعلاف من 1 إلى 3 مم وزيادة معدل سريان الهواء من 15 إلى 25 م^3/دقيقة وزيادة سرعة الدورانية من 200 إلى 800 لفة كل دقيقة، على الترتيب.
- انخفض استهلاك الطاقة النوعى للغذاية من 8.93 الى 7.25 ومن 10.5.76 ومن 10.17 الى 6.51 وات ساعة كجم$^{-1}$ بزيادة مقاس حبيبات الاعلاف من 1 إلى 3 مم وزيادة معدل سريان الهواء من 15 إلى 25 م^3/دقيقة وزيادة سرعة الدورانية من 200 إلى 800 لفة كل دقيقة، على الترتيب.
- انخفضت التكاليف الكلية للغذاية من (0.13 الى 0.10 ومن 0.14 الى 0.09 ومن 0.29 الى 0.05 جنيه كجم$^{-1}$ بزيادة مقاس حبيبات الاعلاف من 1 إلى 3 مم وزيادة معدل سريان الهواء من 15 إلى 25 م^3/دقيقة وزيادة سرعة الدورانية من 200 إلى 800 لفة كل دقيقة، على الترتيب.