Adaptation of cold extrusion technology to produce corn snacks.

Daood[1],V.M., E.A.E. Ali[1], E . Fouda Sally[1]., N.M. El-Bialee[1]

[1]*Bio. Eng. Sys. Res. Department. Agric. Engineering Res., Inst. (AEnRI)., Agric. Res. Center (ARC)., Giza. Egypt.*

---****---

Abstract- *This study aimed to improve the manufacturing process of snacks by modifying a cold extrusion single screw system. The modification involved threading the screw in the opposite direction of the original screw and creating a new reverse screw. Both of original screw "A" and reverse screw "B" were tested at various feeding rates "F", extruder screw speeds "S", and whole die-opening areas "O". The findings showed that, using screw A lead to a positive effect on extruder productivity "Pr" only, meanwhile, it had a negative effects on both of specific mechanical energy "SME", expansion ratio "Er" and void ratio "Vr". On the other hand, F treatment had a direct proportion with both of Pr and SME, while, it had a negative proportion with both of ER and Vr. Over and above, both of SME, Er and Vr were increased by increasing S. Finally, O treatment had an opposite relations with all measured indicators , except Pr.*

***Key words**:* **Extruded snacks, Single Screw Extruder, Reversed Screw.**

INTRODUCTION

Snacks have gained worldwide acceptability and become part of modern food culture, especially among young people [1]. The savory snacks market in Egypt was worth 787.3 M$ in 2020, and is expected to grow by over 9% (≈9.77%) between 2021 and 2028. For example, revenue in the Tortilla Chips, Flips and pretzels market amounts to US$1.77G$ in 2023. Where, the average per capita consumption of savory snacks in Egypt is higher than the regional average [2].

Food industry engineering is consistently developing food product machines using the new technology of food processing such as extrusion. Where, extrusion is a process of shaping and forming a dough-like substance by pushing it through a small opening known as a die. This method is widely employed by the cereal-processing sector to convert cereal flour through kneading, cooking, molding, and texturizing [3].

There is a chance to create brand-new, wholesome, and environmentally friendly extruded snacks [4].

In the extrusion process "EP", starchy, moistened, and food materials are processed through the application of mechanical shear, heat, and pressure [5]. In addition to process have some unique positive features over other thermal processes due to the intense shearing action. The intense shearing action during extrusion can break covalent bonds, cause structural degradation, and alter the physicochemical and functional properties of the extrudates [6].

The EP is a highly versatile (thermal/mechanical process) and cost-effective process comprising operations like shearing, kneading, mixing, cooking, shaping, and forming [7], as well as, including low energy, flexibility, better product quality, and high productivity with very less or almost no process effluents (environmentally friendly)[5 and 8].

The single screw extruder "SSE" is the most commonly used in food industries for developing varieties of extruded products [9]. It contain a single-screw rotating in the metal barrel of the extruder with an axial or helical grooved structure within the inner surface that transports the feed material inside the barrel to the transition zone where the channel depth of the screw decreases and feed material gets compressed and becomes compact [7].

The quality of the products resulting from EP depends on the operating conditions of the extruder, for instance, type of equipment, feed moisture, barrel temperature, screw speed "S" and configuration, and feed rate "F" among other processing parameters [3].

Using high barrel temperature and high feed moisture during EP can result in an increased degree of starch gelatinization, which leads to a higher water absorption index and expansion of the final product. This can also lead to decreased melt viscosity, torque, and "SME". By properly controlling the extrusion proportion and conditions of co-ingredients, a product with better texture, sensory characteristics, and higher nutritional value can be achieved [1].

The optimum temperature during the EP can be achieved by supplying the three sources of energy, namely conductive energy, convective energy, and conversion energy [10].

The extruded snacks production with food by-products will need novel technologies that limit heat damage, during the extrusion process [4].

Cold extrusion is a method used to mix-shape dough without applying direct heat or cooking into the extruder. Heat only shapes the food into different forms by applying pressure material discharged from the barrel through the specific type of die. Where, the material is conveyed from the hopper to the transition section by a rotating screw in the feed section. In the transition section, the screw channel becomes shallower, and the material is compacted, and warmed by friction resulting in a rise in temperature. This causes the starch to become gelatinized, and the material becomes more cohesive. The material is then transported more through the metering section and pushed through the die-opening. Some breakfast products have crisp and light textures, and they extend quickly due to the steam released because of the pressure when the material rises through the die. This technique is mainly used for producing pasta in food processing (5 and 11].

The intrinsic viscosity of maize starch decreased significantly across a set of reverse screw elements. This decrease was caused by the combined effect of shear and heat inputs. They added that, adding reverse-screw elements generally increased the SME and the residence time during twin-screw extrusion [12].

The effects of the extrusion process "EP" parameters, e.g., screw speed "S" (300– 500 rpm), on the functional Er and system "SME" properties of an expanded rice-based snack product. The optimal EP parameters obtained was 323 rpm S [13]. Moreover, the change of S from 300 to 500 rpm favored compound retention by approximately 25%. While, reducing the shear force as a result of increasing the S, lead to reduction on the viscosity of the system [14].

The SME that can be calculated from the torque applied by the extruder motor, the S and the Pr [3]. The SME input also depends on the exact composition of the product being extruded and increases with starch content. A general result is that SME increases when the water content decreases in both of single screw extruder "SSE" and twin –screw extruder "TSS" [15].

In general, screw profiles that have reverse screw elements tend to produce extruded that are more porous and have the highest level of starch breakdown compared to those with kneading blocks. The level of starch breakdown increases systematically when the mixing elements are further from the die, and when the spacing between elements is increased. This, in turn, affects the porosity of the extruded [16].

By modifying a cold extrusion single screw system to produce snacks by cutting the edges of screw bitches as a reversed screw shape opposite the main screw direction without affecting the quality of the product, the authors hope to close some gaps in the design of the SSE in the extended snacks.

MATERIALS and METHODS

The experiments were carried out during the summer season (2020/2021) at a local factory in El-Adabia village, Suez Governorate, using a local single-screw extruder machine (Low-cost), with an original screw (low-shear screw) profile, used to produce snacks for human food. It works at different feeding rates that are controlled by a hopper and multi-speed electrical motor with 1.5 kW. Screw powered by an electric motor with the following specification; Power: 37.3 kW. Operating voltage: 380V. Free running currant: 0.43A.

The extruder screw consists of two equal parts, assembled with a key passing interior incision with a 5 mm diameter between the main shaft and screw to prevent slipping. The first part in the transmission zone is a single screw with 274mm length, 91mm outer diameter, 51mm inner diameter, 3:1 of length – diameter ratio, 12 mm screw channel depth, 21mm screw channel width, and 64 mm of screw pitch.

The second part in the pressing zone on original screw "A" (low shear), is a double screw with dimensions of 10.5mm screw channel width, 32mm of screw pitch, leading and trailing flank angles "α and β"≈ 30°, as well as, screw helix angle "θ" is 15° (Fig.1). While, reverse screw "B" is the second part in the pressing zone on modified screw. It is the double screw with the same previous dimensions, threading in the shape of an inverted isosceles trapezoid (the grand and small bases are 21.5 and 10.5mm) at the opposite direction of the dough movement, with a 12 mm screw channel depth (Fig.2).

The die was fitted at the end of the forming unit. Whole die opening area "O" is the sum of the die holes number × hole area. Four different dies 3, 4, 5 and 6 holes, with constant hole diameters (3mm) were used (Fig.3).

In this study, snack's formula (94.2% corn flour, vegetable oil 4.7%, fiber 0.3%, and flavors 0.8%) was extruded under three considered parameters, in order to

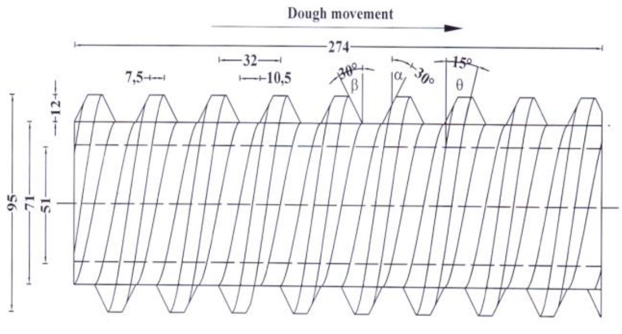

Fig. 1: Original screw "A"

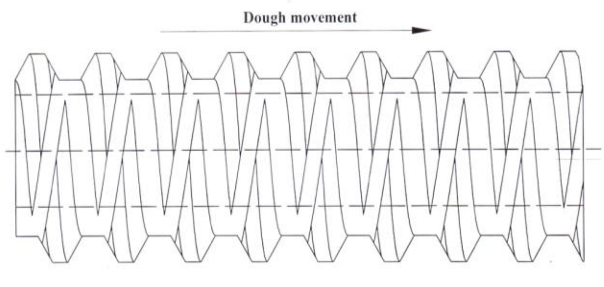

Fig.2: Reverse screw "B"

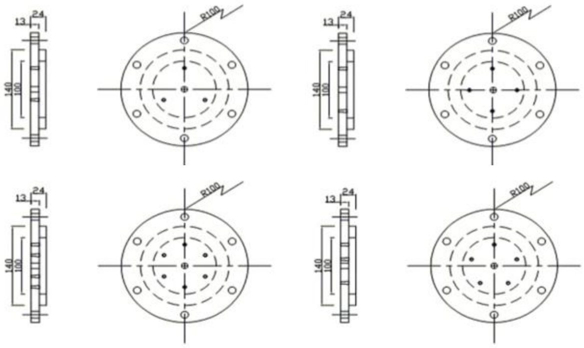

Fig. 3: Different dies.

Evaluate the reverse screw performance comparing with the original screw. These parameters are: i) three feeding rates "F": 375, 400, and 425 kgh^{-1}; ii) extruder screw speed "S": 400 and 450 rpm; iii) Whole die opening area "O": 21.20, 28.27, 35.34, and 42.41 mm^2. Speeds of extruder screw was adjusted and measured by a digital tachometer.

Afterward, a serious measurement was conducted to determine and evaluating the performance and product quality for screw shapes "Sh" in terms of, extruder productivity "Pr" (kgh^{-1}), specific mechanical energy "SME" (kWhkg^{-1}), expansion ratio "Er" (%), and void ratio "Vr" (%).

For each treatment, product outputs were collected for 1 min in the trays, cooled at room temperature and mass recorded by digital balance with an accuracy of 0.01kg after 10 min of regular production. Whilst, super clamp meter-300k, used for measuring the current strength for extruder with and without load. Finally, the 100 randomly snack sample diameters were measured by digital vernier caliper. Then, there were established in the following formula to Pr, SME and Er as follows;

$$\text{Pr} = \frac{P_m \times 60}{T}$$

$$\text{SME} = \frac{\sqrt{3} \times V \times \cos\theta \times \eta}{1000} \times \frac{(I_2 - I_1)}{\text{Pr}}$$

$$\text{Er} = \frac{d^2}{D^2} \times 100$$

Where, Pm is product mass (kg), 60 is converted coefficient from min to h, T is production time (min), $\sqrt{3}$ is resultant three phase current coefficient, V is potential difference voltage (≈ 380 V), Cos θ is power factor (%), η is extruder mechanical efficiency (%), I_2 and I_1 is line current strength amperes for extruder with and without load (A), 1000 is converted coefficient from W to kW, d is average snack piece diameter (mm) and D is die hole diameter (mm).

On the other hand, a cross section of snack sample was measured by an electronic microscope model (JOEL - 7500), at the Egyptian laboratory Centre of the agriculture research Centre, Giza Each treatment was replicated, to study the snack's microstructure. The hereafter eq. used to calculate the void ratio "Vr" (%).

$$\text{Vr} = \frac{\text{Section of snack sample void area}}{\text{Section of snack sample total area}} \times 100$$

RESULTS and DISCUSSIONS

Generally, the attained results of extruder performance in terms of productivity "Pr" (kgh^{-1}) revealed that, the performance of screw A is more than screw B. Likewise, there were direct proportional relations between Pr and both of O and F. On the other hand, the relation between Pr and S is mixture relation. It had negative relation with all F treatments for both Sh (A and B) at O_1 and O_2, while, it had direct relation with other O (O_3 and O_4). Referring to the effect of the Sh, at O_4 (42.41mm^2), Pr decreased with rate of 3.97, 3.90 and 3.84% by using screw B instated of screw A , with S_2, at F_1, F_2 and F_3 respectively. Moreover, Pr had fallen with rate of 3.85, 4.34 and 4.27% with S_1 and the same previous circumstances. Pr reductions are influenced by a changed B screw owing to the higher retention period of the formula within the extrusion barrel. This is consistent with [5,8,17 and 18].

With using screw A (original screw) at S_2 & O_4 (450 rpm & 42.41mm^2) treatment, Pr had risen from 195.70 to 199.22 up to 201.91 kgh^{-1} by increasing F from F_1 (375 kgh^{-1}) to F_2 (400 kgh^{-1}) up to F_3 (425 kgh^{-1}), also, with using screw B (reverse screw) at same previous conditions, Pr rose from 187.95 to 191.46 up to 194.15 kgh^{-1}. By expanding "O" from 21.20 to 42.41 mm^2, with utilizing screw A & S_2 treatment, Pr improved about 133.96, 137.11 and 139.16 kgh^{-1}, at F_1, F_2 and F_3, respectively. The same trend is exhibited by employing screw A & S_1. Pr rises by increasing S, F, and O owing to increasing generated mass per time unit (Chart -1).

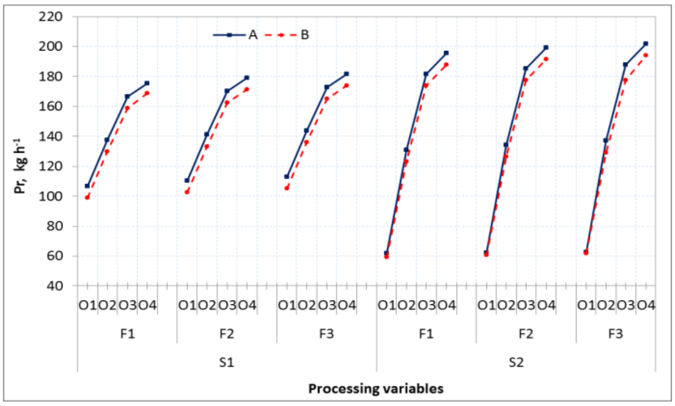

Chart-1: Effects of processing variables on Pr.

Specific mechanical energy "SME" measured energy consumption by extruder to produce one kilogram of snacks. Generally, the SME values for screw A are less than B through all treatments. The values of SME for screw A ranged from 31.35 to 116.31kWhkg^{-1} and 39.69 to 243.10kWhkg^{-1} at S_1 and S_2. While, it ranged from 40.59 to 135.65 kWhkg^{-1}, and from 48.28 to 261.89 at S_1 and S_2 with using screw B, as shown in chart-2. There was a negative relation between SME values and O. This relation because of the growing productivity of the extruder. Where, at screw A with S_1, increasing O from 21.20 to 42.41 mm^2, lead to dropped SME values about 73.16, 76.25 and 73.26 kWhkg^{-1} and 177.79, 195.72 and 170.74 kWh kg^{-1} at F_1,F_2 and F_3, respectively. While, the values were dropped about 85.30, 86.41 and 79.69 kWhkg^{-1}, and 199.73, 208.36 and 188.15 kWhkg^{-1}, with the same previous arrangement, at screw B & S_1 and S_1. On the other hand, there was a direct relation between SME values and S at all current variables under study. Where, increasing S from S_1 to S_2 at O_4 (42.41mm^2), lead to increase SME values about 112.98, 126.78 and 104.09 kWhkg^{-1} with screw A, and about 122.13, 128.87and 110.10 kWhkg^{-1} with screw B, at F_1,F_2 and F_3, respectively. In contrast, its value had a negative relation with O. These results owing to increase in power consumption and retention time of the whole extrusion process.

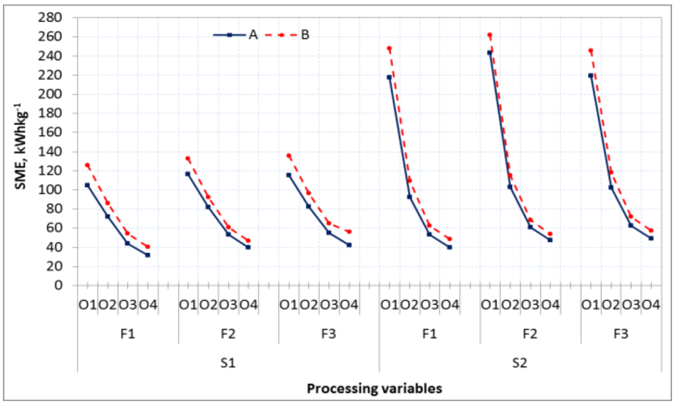

Chart-2: Effects of processing variables on SME.

The Er regarded is the most essential component of snack quality since it indicates to snack crispness. It is clear that with using original screw (A) at S_1 (400rpm) the Er (%) reduced about 22.71, 24.75 and 26.84% by increasing O from O_1 to O_4 (≈21.2 to 42.41mm^2) at F_1, F_2 and F_3 (375, 400 and 425 kgh^{-1}) respectively. Meanwhile, the reduction percentages were reaching to 20.16, 21.76 and 23.36% with using modified screw (B) under the same circumstances. The reduction in the Er generated by increasing the O was attributable to low pressure and temperature within the extrusion barrel. Also, the Er dropped by raising the F because of the rise in productive mass with fewer interspaces. On the other hand, by employing O_4, increasing S from S_1 to S_2 (400 to 450rpm), lead to augmented Er about 4.43,4.95 and 5.53% at screw A and about 3.81,4.19 and 4.59% at screw B on F_1, F_2 and F_3, respectively. Regarding the impact of screw A (original screw) compared with modified screw ("B" reverse screw) employing the previous O, the ER rose about 16.30, 18.24 and 20.35% at S_1 and 15.61, 17.38 and 19.29% at S_2 with F_1, F_2 and F_3, respectively. Increase in Er by running modified screw (B) owing to increased retention time, which implies greater fraction particle time, creating an increase in pressure and temperature within the cylinder and boosting the efficiency of the gelatinized process after departure (Chart-3).

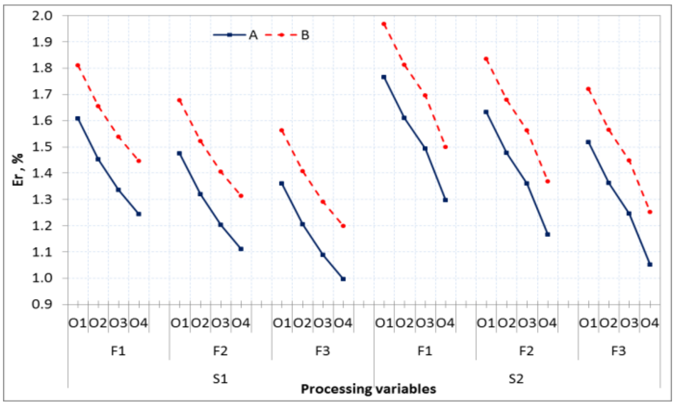

Chart-3: Effects of processing variables on Er.

It is clear from table (1) that by using reverse screw (B) comparing with original screw (B), the void ratio "Vr" had increased with rate of 12.60, 13.94, 15.17 and 16.30% at O of 21.20, 28.27, 35.34 and 42.41 mm^2 (O_1, O_2, O_3 and O_4) respectively, at S_1&F_1 treatment. Furthermore, the Vr had a direct proportion with S. With using original screw (A) at O of 21.20 mm^2 (O_1), it rose with rate of 10.85, 11.74 and 12.65% by raising S from S_1 to S_2 (400 to 450 rpm) at F_1, F_2 and F_3 (375, 425, and 475 kg h^{-1}) respectively.

Similarly, the Vr demonstrated the same pattern by employing reverse screw (B) under the same circumstances. Increasing Vr by increasing S and changing screw owing to increasing retention time, the formula faced high pressure and temperature for a longer time, which led to increased expansion and interspaces after the extrusion process. The Vr had an inverse relation with O at all treatments. At S_1 (400 rpm) and by expanding O to double (from ≈ 21.20 to 42.41 mm^2), the Vr reduced wit rate of 22.71 and 20.17% at F_1, 24.75 and 21.76% at F_2, and 26.84 and 23.36% at F_3 with using screw A and B. A similar tendency was found at S_2 with varied F. The reduction in Vr generated by expanding O might be attributed to reducing pressure and temperature within the extrusion barrel. Likewise, the Vr had a negative relation with F. With using screw A & S_1, it dropped about 9.75% by increasing F from F_1 to F_3 at O_1 (21.20 mm^2). The Vr exhibited the same trend at screw B& S_2, with utilizing various O. This negative relation is owing to an increase in mass structure versus volume.

Table 1: Void ratio (%) Vs. S, Sh, F and O.

F (kg h^{-1})	S (rpm)	$S_1 \approx 400$		$S_2 \approx 450$	
	Sh / O (mm^2)	A	B	A	B
$F_1 \approx 375$	$O_1 \approx 21.20$	63.30	71.27	70.16	78.21
	$O_2 \approx 28.27$	57.19	65.17	64.00	72.05
	$O_3 \approx 35.34$	52.57	60.54	59.33	67.38
	$O_4 \approx 42.41$	48.92	56.90	51.58	59.63
$F_2 \approx 400$	$O_1 \approx 21.20$	58.08	66.05	64.90	72.95
	$O_2 \approx 28.27$	51.98	59.95	58.74	66.79
	$O_3 \approx 35.34$	47.35	55.32	54.06	62.11
	$O_4 \approx 42.41$	43.71	51.68	46.31	54.36
$F_3 \approx 425$	$O_1 \approx 21.20$	53.55	61.52	60.33	68.38
	$O_2 \approx 28.27$	47.45	55.42	54.16	62.21
	$O_3 \approx 35.34$	42.82	50.79	49.49	57.54
	$O_4 \approx 42.41$	39.18	47.15	41.74	49.79

CONCLUSION

By using a newly developed reverse screw in a local extruder, cold extrusion can be optimized for maximum utilization. Comparing the results of using the reverse screw (B) versus the original screw (A) to make snacks at F varying F, S, and O, the following findings were observed:

The "Pr" increased as the F sequentially rose with an increase in the "O" and utilization of "B" screw. Furthermore, the increases in Pr by increasing S, F, and O, due to the increased generated mass per time unit.

Increased O lead to a decrease in the SME in both of A and B screws. This reduction was due to increased Pr. In contrast, increasing both of F and S, and changing screws (A to B) lead to increased SME due to increased power consumption and retention duration.

The Er is important as it indicates crispness. It was observed that using a modified version of screw "B" lead to increase the Er at all F. This was due to an increase in retention time, which allowed for a greater fraction of particle time. This created an increase in pressure and temperature within the cylinder, boosting the efficiency of the gelatinized process after departure.

The Vr increased by using modified screw B compared to screw A at both S and F. Additionally; the Vr increased when S was increased using screw B. This increase in the Vr was due to a longer retention time, resulting in higher pressure and temperature during extrusion, leading to more expansion and interspaces. Conversely, the Vr decreased when O was increased using screws A and B at both F and S.

REFERENCES

[1]G. P. Yadav, C. G. Dalbhagat, and H. N. Mishra "Effects of extrusion process parameters on cooking characteristics and physicochemical, textural, thermal, pasting, microstructure, and nutritional properties of millet-based extruded products: A review. Journal of Food Process Engineering, vol.45, Issue 9 Sep. 2022, pp.1-25. John Wiley and Sons Inc. doi: 10.1111/jfpe.14106

[2] Global-Data, "Egypt Savory Snacks Market Size, Share & Trends Analysis and Forecast by Category, Product Attributes, and Consumer Benefits 2021-2025". 2021.

[3] J. M. Bouvier, and O.H. Campanella, "Extrusion processing technology" Extrusion Processing Technology: Food and Non-Food Biomaterials Handbook. (2014). doi: 10.1002/ 9781118541685.

[4] S. Grasso, "Extruded snacks from industrial by-products: A review". Trends in Food Science and Technology, vol.99, Issue 5, May. 2020, pp. 284–294. Elsevier Ltd. doi: 10. 1016/j.tifs.2020.03.012.

[5] G. A. Shelar, and S. T. Gaikwad, "Extrusion in food processing: An overview". The Pharma Innovation Journal, vol. 8, Issue 2 Feb. 2019, pp.562-568.

[6] S. Singh, S. Gamlath, and L. Wakeling, "Nutritional aspects of food extrusion: A review". International Journal of Food Science and Technology, vol.42, Issue 8 Aug. 2007, pp.916-929. doi: 10.1111/j.13652621. 2006.01309.x.

[7] C. G. Dalbhagat, D. K. Mahato, and H. N. Mishra, "Effect of extrusion processing on physicochemical, functional and nutritional characteristics of rice and rice-based products: A review". Trends in Food Science & Technology, vol 85, Issue 5, Mar. 2019, pp. 226–240. doi: 10.1016/J.TIFS. 2019.01.001

[8] A. Sukumar, and K. A. Athmaselvi, "Optimization of process parameters for the development of finger millet based multigrain extruded snack food fortified with banana powder using RSM". Journal of Food Science and Technology, vol. 56 Issue 2 Feb. 2019, pp.705-712. doi: 10.1007/ s13197-018-3527-x.

[9] S. A. Navale, S. B. Swami, and N. J. Thakor, " Extrusion cooking technology for foods : A review". Journal of ready to eat food, vol. 2, Issue 3, Mar. 2015, pp.66.80.

[10]M. Maskan, and A. Altan, "Advances in food extrusion technology". Advances in Food Extrusion Technology Handbook (1st Edition). CRC Press. 2016. doi: 10.1201 /b11286.

[11]H. G. Ramachandra rao, and M. L. Thejaswini, "Extrusion Technology: A novel method of food processing". International Journal of Innovative Science, Engineering & Technology, vol.2, Issue4, Apr. 2015, pp.358-369.

[12]K. L. Yam, B. K. Gogoi, M.V. Karwe, and S. S. Wang, "Shear conversion of corn meal by reverse screw elements during twin-screw extrusion at low temperatures" Journal of Food Science, vol. 59, Issue 1 Jan. 1994, pp.113-114. doi: 10.1111/j.1365-2621. 1994. tb06910.x

[13]M.S. Alam, S. Kumar, and H. Khaira, "Effects of extrusion process parameters on a cereal-based ready-to-eat expanded product formulated with carrot pomace". Cereal Foods World, vol. 60, Issue 6. Jun. 2015, pp. 287-295. doi: 10.1094/CFW-60-6-0287.

[14]L. S. Pinho, C. E. C. Rodrigues, C. S. Favaro-Trindade, and O. H. Campanella, "The incorporation of caroteneoids on ready to eat foods studied through their stability during extrusion processing". Food Engineering Reviews, vol. 13, Issue 4, Apr. 2021, pp.902-915. doi: 10.1007/s12393-021-09285-w.

[15]T. Ajita, "Extrusion cooking technology: An advance skill for manufacturing of extrudate food products". Extrusion of Metals, Polymers and Food Products Handbook. 2018. doi: 10.5772/intechopen.73496.

[16]A. Gautam, and G. S. Choudhury, "Screw configuration effects on starch breakdown during twin-screw extrusion of rice flour". Journal of Food Processing and Preservation, vol. 23, Issue 5, May. 1999, pp.325-375.doi: 10.1111/j. 1745-4549.1999.tb00391.x

[17]R. Guy, "Raw materials for extrusion cooking". Extrusion Cooking Handbook. In Robin Guy (Ed.) Wood head Publishing. 2001, pp. 5-28. doi: https://doi.org/10.1533/ 9781855736313.1.5.

[18]V. Daood, M. M. Morad, M. Afify, and O. A. Kadour, "Development of a single screw extruder for improving the quality of expanded". Zagazig J. Agric. Res., vol.41, Issue 4, Apr. 2014, pp. 863–876.