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Comparative study of cabinet drying and microwave drying for murrel fish (*Channa marulius*) drying

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Abstract
Murrel fish (*Channa marulius*) is an important freshwater fish valued for its high-quality protein and nutritional characteristics. However, its high moisture content makes it highly perishable and creates difficulties in storage, transportation, and marketing. Drying is an established preservation technique that reduces moisture availability and thereby limits microbial and enzymatic deterioration. The present study compared conventional cabinet drying with microwave drying for the dehydration of murrel fish and evaluated drying kinetics, drying time, yield, water activity, rehydration characteristics, proximate composition, antioxidant activity, texture, and colour. Fresh murrel fish were cleaned, dressed, cut into uniform pieces, and pretreated using 10% sodium chloride solution for 2 h. For cabinet drying, samples were dried at 60 °C with an air velocity of approximately 0.5 m/s. Microwave drying was carried out at 540, 720, and 900 W. The cabinet-drying process required approximately 12 h, whereas microwave treatments substantially reduced processing time, with recorded drying times of 36, 34, and 28 min at 540, 720, and 900 W, respectively. Increasing microwave power accelerated moisture removal but resulted in progressively lower rehydration ratio and higher specific energy consumption. The 720 W treatment provided a practical balance between drying efficiency and product quality. Cabinet-dried fish contained 12.81 ± 0.22% moisture and 61.27 ± 0.34% protein, whereas the microwave treatments produced moisture contents of 7.37 ± 0.63, 3.06 ± 0.10, and 4.72 ± 0.58% and protein contents of 78.75 ± 0.30, 77.67 ± 0.32, and 85.14 ± 0.19% at 540, 720, and 900 W, respectively. Overall, microwave drying was substantially faster than cabinet drying and produced fish powder with favourable physicochemical characteristics. Among the microwave conditions, 720 W was identified in the research as the most suitable condition because it provided a balance among drying rate, energy consumption, nutritional quality, colour, texture, and rehydration properties.

Keywords: Murrel fish, *Channa marulius*, cabinet drying, microwave drying, drying kinetics, fish powder, moisture content, protein, rehydration ratio

1. Introduction

Fish is an essential component of the human diet and provides valuable nutrients, including high-quality protein, omega-3 fatty acids, vitamins, minerals, and essential amino acids. However, fresh fish is highly perishable, creating significant challenges for storage, transportation, and marketing. Drying is one of the oldest and most widely used methods of fish preservation because removal of moisture reduces microbial growth and enzymatic activity responsible for spoilage (Guiné, 2018; Fitri *et al.*, 2022; Saklani *et al.*, 2024) [2, 1, 3]. Traditional drying methods, particularly sun drying, are economical and relatively simple; however, their efficiency and product quality are strongly influenced by environmental conditions. Exposure to uncontrolled temperature, humidity, insects, and contamination can adversely affect the quality and safety of dried fish. Conventional hot-air or cabinet drying provides better control over temperature and ventilation, but it generally requires longer drying periods and prolonged exposure to heat may contribute to nutrient degradation and deterioration of colour, texture, and other quality attributes (Guiné, 2018; Fitri *et al.*, 2022; Alam, 2024) [2, 1, 4].

Microwave drying has emerged as an advanced alternative dehydration technology because electromagnetic energy interacts directly with water molecules within the food matrix, generating heat internally. This volumetric heating mechanism differs from conventional hot-air drying, in which heat is transferred primarily from the surface toward the interior. Internal microwave heating promotes rapid moisture evaporation and can considerably reduce drying time (Drouzas & Schubert, 1996; Guttifera *et al.*, 2022; Ramachandran *et al.*, 2024; Verma *et al.*, 2024) [5, 6]. Previous studies have reported that microwave drying can improve drying efficiency and reduce processing time while offering favourable retention of nutritional and sensory characteristics compared with conventional drying methods (Drouzas *et al.*, 1996; Dadali *et al.*, 2007; Ozkan *et al.*, 2007) [5, 7, 8].

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Murrel, particularly *Channa marulius*, is an economically important freshwater fish distributed across South and Southeast Asia and is recognized for its high meat quality, good yield, market demand, and potential for aquaculture (Rabbani *et al.*, 2024; Khan *et al.*, 2023) [10, 9]. The species is also nutritionally valuable, with reported protein contents of approximately 16.9 g/100 g in fresh muscle, while studies of its body composition and amino-acid profile further demonstrate its nutritional importance (Jabeen *et al.*, 2016) [11]. In addition, *Channa marulius* has traditionally been valued for its food and perceived recuperative properties. Although drying has been investigated extensively for fish and aquatic products, specific published studies on microwave drying of *Channa marulius* remain limited, providing a rationale for investigating microwave processing as an alternative to conventional drying. This is particularly relevant because microwave processing has been reported to reduce drying time and energy consumption and to improve or maintain several physicochemical quality attributes of fish products (Kipcak & İsmail, 2021; Qin *et al.*, 2020; *Trends in Food Science & Technology*, 2022) [12, 13].

Previous studies support the potential of microwave drying for fish and other aquatic products. Microwave drying of sardine fish demonstrated that increasing microwave power substantially reduced drying time, with drying occurring predominantly during the falling-rate period (El-Hadary *et al.*, 2013). Similarly, microwave drying of fish, chicken, and beef has demonstrated the applicability of microwave energy for rapid moisture removal (Kipcak *et al.*, 2021) [12]. Studies combining microwave and hot-air drying of grass carp fillets have also reported improved quality characteristics compared with conventional hot-air drying, with microwave treatment influencing drying time, colour, hardness, and rehydration properties (Qin *et al.*, 2020) [13]. These findings support the investigation of microwave drying as a rapid and potentially effective alternative to conventional cabinet drying for the production of dried *Channa marulius* products.

Therefore, the present study was undertaken to compare cabinet drying and microwave drying of murrel fish with particular emphasis on drying behaviour, drying time, nutritional composition, rehydration, colour, texture, water activity, energy consumption, and suitability for fish-powder production.

2. Objectives

The principal objectives of the study were:

1. To standardize pretreatment and drying conditions for murrel fish.
2. To compare cabinet drying and microwave drying for the dehydration of murrel fish.
3. To evaluate drying kinetics, drying time, yield, moisture content, water activity, and rehydration characteristics.
4. To compare the proximate composition, antioxidant activity, colour, and textural characteristics of fish dried using the two methods.
5. To identify a suitable microwave power for producing high-quality murrel fish powder.

3. Materials and Methods

3.1 Raw material

Freshwater murrel fish (*Channa marulius*) was procured from the local market of Chhatrapati Sambhajinagar, Maharashtra, India. The fish was transported under chilled conditions and processed promptly. The materials used included fresh murrel fish, analytical-grade sodium chloride, distilled water, and other ingredients required for subsequent fish-powder and fish-chip preparation.

3.2 Preparation and pretreatment

The fish was eviscerated, cleaned, washed thoroughly, and cut into uniform darne-shaped pieces. Sodium chloride solutions were prepared for pretreatment. Based on the optimization experiments, 10% NaCl was selected as the optimum pretreatment concentration. Fish samples were immersed in the salt solution for 2 h, after which excess surface brine was drained before drying. A sample-to-brine ratio of 2:1 (g/mL) was maintained, and treatments were conducted in triplicate.

3.3 Optimization of cabinet drying

A Central Composite Design within Response Surface Methodology was used to evaluate the effects of drying temperature and NaCl concentration. Drying temperatures of 50, 60, and 70 °C and NaCl concentrations ranging from 0 to 20% were investigated. Moisture content, protein, fat, and rehydration ratio were used as response variables.

The numerical optimization identified **60 °C drying temperature and 10% NaCl pretreatment** as the optimum cabinet-drying condition. The optimized responses were moisture content 12.810%, protein 61.250%, fat 2.850%, and rehydration ratio 14.510, with a desirability value of 1.000.

3.4 Cabinet drying

The pretreated fish pieces were arranged uniformly on cabinet-dryer trays. The cabinet dryer was operated at 60 °C, and air velocity was maintained at approximately 0.5 m/s. Sample weights were recorded at 2-h intervals. Drying was continued until the desired moisture level was reached. The research reports that the drying process extended to approximately 12 h under the selected cabinet-drying condition.

3.5 Microwave drying

Pretreated fish samples were dried using microwave power levels of 540, 720, and 900 W. Sample weight was monitored at 2-min intervals until the target moisture condition was reached. The dried fish was subsequently ground and passed through a 500-µm sieve to obtain uniform fish powder.

The microwave treatments were designated as:

- **MMD1:** 540 W
- **MMD2:** 720 W
- **MMD3:** 900 W

3.6 Drying kinetics

Moisture content was determined on wet and dry bases. Drying rate and moisture ratio were calculated from the change in moisture content with time. The research monitored the reduction in moisture content during both cabinet and microwave drying to characterize drying behaviour.

3.7 Rehydration ratio

Dried samples were immersed in water maintained at approximately 40 °C for 30 min. The samples were subsequently removed and weighed, and the rehydration ratio was calculated. Three replicates were conducted for each treatment.

3.8 Proximate composition

The proximate composition of the dried *Channa marulius* samples was determined using standard analytical procedures described in the research. Moisture content was determined by the oven-drying method, ash content by furnace incineration, crude protein by the Kjeldahl method, and crude fat by Soxhlet extraction. Crude fibre, carbohydrate, and energy values were also determined/calculated according to the analytical procedures described in the research. These methods are commonly used for evaluating the nutritional composition of dried fish products (AOAC, 2005; AOAC, 2019) [14]. The analyses were conducted to evaluate the nutritional composition and to assess changes in the proximate characteristics of murrel fish resulting from cabinet and microwave drying.

3.9 Texture and colour

Texture profile analysis was used to assess properties such as hardness, adhesiveness, cohesiveness, springiness, gumminess, and chewiness. Colour was measured using a Chroma Meter using L^*, a^*, and

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b^* values. Derived colour parameters included total colour difference, chroma, hue angle, whiteness index, and browning index.

4. Results and Discussion

4.1 Optimization of cabinet drying

The Response Surface Methodology experiments demonstrated that drying temperature and NaCl concentration influenced the physicochemical properties of dried murrel fish. The optimized cabinet condition was 60 °C with 10% NaCl pretreatment. Under these conditions, the predicted/optimized moisture content was 12.81%, protein content 61.25%, fat content 2.85%, and rehydration ratio 14.51, with an overall desirability of 1.000.

The moisture-content model showed strong statistical performance, with $R^2 = 0.9851$, adjusted $R^2 = 0.9745$, and predicted $R^2 = 0.8944$. The ANOVA indicated that temperature and the temperature–salt interaction were important contributors to moisture content.

The results demonstrate that controlled hot-air drying can produce a nutritionally concentrated and stable dried fish product. However, the major limitation of the cabinet process was the relatively long drying period.

4.2 Drying behaviour of cabinet-dried murrel fish

During cabinet drying, moisture content on a dry basis declined continuously from approximately 255% to around 16% after 12 h. Moisture reduction was rapid during the early stages because free water was readily evaporated. As drying progressed, the rate decreased because moisture became increasingly bound within the fish tissue and internal moisture diffusion became the dominant resistance.

The moisture ratio declined from approximately 1.0 at the beginning of drying to around 0.06 after 12 h. The drying rate was approximately 0.84 g/h during the first hour, decreased to approximately 0.42 g/h during the second hour, and subsequently declined to below 0.05 g/h toward the end of the process. This indicates predominantly falling-rate drying behaviour.

The prolonged falling-rate period is a major process limitation of conventional cabinet drying. Although the method provides controlled temperature and airflow, moisture transfer from the interior of the fish becomes progressively slower.

4.3 Drying behaviour of microwave-dried murrel fish

Microwave drying produced considerably faster moisture removal than cabinet drying. Increasing microwave power from 540 to 720 and 900 W increased the drying rate and reduced the required processing time. The research reports that the highest power generated the greatest internal heating and consequently accelerated water evaporation.

The microwave drying-rate curves showed an initially high drying rate followed by a gradual decline. At 900 W, the peak drying rate was approximately 0.29 g/min around the fifth minute. The 720 W treatment showed intermediate drying rates, generally between approximately 0.12 and 0.18 g/min, whereas 540 W produced the lowest rates.

These results confirm that microwave power is a critical operating variable. Greater microwave power provides faster volumetric heating and moisture removal, but the highest power does not necessarily produce the best overall product because excessive processing intensity can negatively affect energy efficiency, rehydration, antioxidant activity, and texture.

4.4 Comparison of drying time

The difference between the two technologies was particularly pronounced in drying time.

Table 1. Comparison of Drying Time of Cabinet-Dried and Microwave-Dried Murrel Fish

Drying method/treatment	Drying condition	Recorded drying time
Cabinet drying	60 °C	Approximately 12 h
Microwave MMD1	540 W	36 min
Microwave MMD2	720 W	34 min
Microwave MMD3	900 W	28 min

The microwave process reduced drying time dramatically. In the present study, cabinet drying at 60 °C required approximately 12 h, whereas microwave drying required only 36 min at 540 W, 34 min at 720 W, and 28 min at 900 W. Relative to the cabinet process, the 720 W treatment reduced processing time by approximately 95.3%, while the 900 W treatment achieved a reduction of approximately 96.1%. This substantial reduction demonstrates the major time-saving potential of microwave drying for *Channa marulius*.

The present findings are consistent with previous research demonstrating that increasing microwave power increases the drying rate and consequently decreases drying time. Darvishi *et al.* (2013) [15], in their study of sardine, reported that increasing microwave power from 200 to 500 W reduced drying time from 9.5 to 4.25 min, with drying occurring predominantly during the falling-rate period. Similarly, Kipcak *et al.* (2021) [12] observed that the drying time of fish decreased progressively as microwave power increased from 90 to 360 W, with fish requiring approximately 12, 8, 5, and 3 min, respectively. The authors attributed the increased drying rate at higher microwave power to greater internal heat generation and increased vapour-pressure differences within the product.

Comparable results have also been reported for other fish-drying systems. In tilapia fillets, hot-air–microwave drying substantially reduced dehydration time, and increasing microwave power enhanced moisture removal, although the study emphasized that lower microwave power and temperature could be beneficial for maintaining product quality (Duan *et al.*, 2011) [16]. More recently, Taşova *et al.* (2023) [17] reported that microwave drying of shad required only 57.5 min at 360 W and 7.5 min at 720 W, compared with much longer times for temperature-controlled microwave drying, further demonstrating the strong influence of microwave energy on drying kinetics.

Thus, the 95–96% reduction in drying time observed in the present study is consistent with the general trend reported in previous studies, although the magnitude of reduction should be interpreted specifically for the experimental conditions used for *Channa marulius*. Microwave drying therefore offers a major processing advantage where rapid dehydration, reduced processing time, and high production throughput are important. However, increased microwave power should not be evaluated solely on drying speed because excessive power may adversely affect characteristics such as texture, colour, and rehydration. The optimum microwave condition should consequently balance drying time, energy consumption, and final product quality. The research findings similarly indicate that microwave drying was substantially faster and more efficient than cabinet drying under the investigated conditions.

4.5 Drying yield, water activity and rehydration

The microwave treatments showed relatively similar drying yields despite differences in microwave power. The recorded yields were 33.56%, 33.32%, and 32.98% for 540, 720, and 900 W, respectively. Water activity was 0.58 for both 540 and 720 W and decreased slightly to 0.55 at 900 W.

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Table 2. Drying Time, Yield, Water Activity and Rehydration Ratio of Microwave-Dried Murrel Fish

Treatment	Power	Drying time (min)	Yield (%)	Water activity	Rehydration ratio
MMD1	540 W	36	33.56	0.58	0.20
MMD2	720 W	34	33.32	0.58	0.17
MMD3	900 W	28	32.98	0.55	0.14

The rehydration ratio of microwave-dried *Channa marulius* decreased progressively with increasing microwave power, declining from 0.20 at 540 W (MMD1) to 0.17 at 720 W (MMD2) and 0.14 at 900 W (MMD3). This trend indicates that although higher microwave power accelerated moisture removal, it adversely affected the rehydration capacity of the dried fish. The decline in rehydration ratio may be associated with greater structural changes in the fish tissue at higher microwave power, which can reduce the ability of the dried matrix to absorb and retain water during rehydration.

This finding demonstrates an important trade-off between drying rate and product rehydration quality. Higher microwave power provides faster dehydration, but excessive microwave intensity may result in greater structural damage and consequently poorer rehydration characteristics. Similar effects have been reported in microwave-assisted drying studies, where increasing microwave intensity or treatment severity was associated with changes in tissue structure and rehydration behaviour. Qin *et al.* (2020) [13] reported that microwave treatment affected the rehydration properties and structural characteristics of grass carp fillets, while microwave drying studies on fish have demonstrated that processing conditions strongly influence the final quality of the dried product. Therefore, the 720 W treatment may represent a more balanced condition than 900 W when both drying speed and product quality are considered, rather than selecting the highest microwave power solely on the basis of drying time.

4.6 Comparison of proximate composition

The cabinet-dried fish contained 12.81 ± 0.22% moisture, 21.24 ± 0.56% ash, 2.85 ± 0.24% fat, 2.93 ± 0.24% crude fibre, and 61.27 ± 0.34% protein. Its energy value was 271.18 ± 22.47 kcal/100 g, while antioxidant activity was 49.96 ± 0.51%.

Table 3. Proximate Composition of Cabinet-Dried and Microwave-Dried Murrel Fish

Parameter	Cabinet, 60 °C	MMD1, 540 W	MMD2, 720 W	MMD3, 900 W
Moisture (%)	12.81 ± 0.22	7.37 ± 0.63	3.06 ± 0.10	4.72 ± 0.58
Ash (%)	21.24 ± 0.56	27.47 ± 0.35	25.10 ± 0.19	22.92 ± 0.25
Fat (%)	2.85 ± 0.24	3.35 ± 0.35	6.17 ± 0.19	8.13 ± 0.20
Crude fibre (%)	2.93 ± 0.24	1.18 ± 0.19	1.19 ± 0.01	2.08 ± 0.16
Protein (%)	61.27 ± 0.34	78.75 ± 0.30	77.67 ± 0.32	85.14 ± 0.19
Energy (kcal/100 g)	271.18 ± 22.47	345.14 ± 4.6	364.09 ± 6.3	416 ± 2.29

The microwave-dried *Channa marulius* samples showed substantially higher apparent protein concentrations than the cabinet-dried sample. In the present study, protein concentration increased from 61.27% in cabinet-dried fish at 60 °C to 78.75%, 77.67%, and 85.14% at 540, 720, and 900 W, respectively. The highest protein concentration was therefore recorded at 900 W, whereas the lowest moisture content among the microwave treatments was observed at 720 W (3.06%). These results are broadly consistent with previous studies showing that drying can increase the measured protein percentage of fish products as moisture is removed. Wu *et al.* (2008) [18], for example, reported that drying grass carp fillets by both hot-air and microwave methods significantly increased the measured protein content, while moisture was the most prominent component lost during drying.

A similar trend was reported by Akhtar *et al.* (2022) [19] for *Puntius sophore*, where increasing microwave treatment resulted in decreasing moisture content and increasing measured protein content. The authors concluded that microwave drying could be used effectively for fish preservation while increasing the apparent protein concentration of the dried product. These observations are also supported by research on microwave-vacuum-dried rohu (*Labeo rohita*), in which protein concentration increased from 14.94% in fresh fish to 67.28% in the dried fish powder, while moisture decreased from 75.46% to 4.52%.

The increase in protein concentration in the present study should, however, be interpreted primarily as a concentration effect resulting from moisture removal, rather than as an actual increase in the absolute amount of protein present in the fish. When water is removed during drying, the remaining solids constitute a larger proportion of the total sample mass, causing protein, ash, fat, and other solid components to appear at higher percentages when expressed on a wet-weight basis. This interpretation is consistent with studies of dried fish in which substantial reductions in moisture were accompanied by increases in the measured concentrations of protein and ash.

Importantly, the present results should not be interpreted as evidence that microwave treatment at 900 W produced more protein than cabinet drying. Rather, the higher value indicates a greater proportion of protein in the final dried material. A true comparison of protein retention would require calculation on a dry-matter basis and/or comparison of total protein mass before and after drying. Therefore, although the 900 W treatment produced the highest apparent protein concentration, the 720 W treatment may still provide a more balanced drying condition when moisture removal, processing time, rehydration, texture, and other quality characteristics are considered. This interpretation is consistent with previous work showing that microwave power strongly affects moisture removal and drying kinetics, while the resulting nutritional composition depends on the extent and conditions of dehydration. Kipcak *et al.* (2021) [12], for example, demonstrated that increasing microwave power accelerated moisture removal in fish samples, although their study focused primarily on drying kinetics rather than demonstrating an increase in absolute protein content.

4.7 Antioxidant activity

Antioxidant activity varied with microwave power. The values were 53.61 ± 1.80% at 540 W, 48.90 ± 1.20% at 720 W, and 46.44 ± 1.17% at 900 W.

The reduction in antioxidant activity with increasing microwave power suggests that more intense thermal treatment may adversely affect some antioxidant compounds. Therefore, although 900 W produced the fastest drying and highest protein concentration, it did not provide the best balance of all quality characteristics.

The cabinet-dried product showed antioxidant activity of 49.96 ± 0.51%. Thus, the 540 W microwave treatment showed the highest antioxidant activity among the compared microwave conditions, while 720 W remained relatively close to the cabinet treatment.

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4.8 Specific energy consumption

Specific energy consumption increased with microwave power. The recorded values were 69.57 W min/g water evaporated at 540 W, 70.54 W min/g at 720 W, and 72.20 W min/g at 900 W.

Therefore, although 900 W shortened the drying period, it required more specific energy per unit of water removed. The 540 W treatment was the most energy-efficient of the microwave treatments. The 720 W treatment showed only a modest increase in specific energy consumption relative to 540 W while providing faster drying and favourable product characteristics.

This demonstrates that the fastest treatment is not necessarily the most energy-efficient treatment. For industrial application, both throughput and energy use should be considered.

4.9 Textural properties

The cabinet-dried fish exhibited a hardness of 3388 g, adhesiveness of 0.10 mJ, cohesiveness of 0.63, springiness of 3.33 mm, gumminess of 4261 g, and chewiness of 174.00 mJ. The results indicated a firm, cohesive, moderately elastic, and relatively non-sticky dried product.

The research comparison indicates that the 720 W microwave treatment produced a desirable intermediate texture. At 900 W, the product became harder and less elastic, while the 540 W treatment produced a softer texture but required longer processing. Consequently, 720 W was considered a suitable compromise between process speed and textural quality.

4.10 Colour characteristics

Cabinet-dried murrel exhibited L^* = 34.1 ± 1.3, a^* = 6.4 ± 0.6, b^* = 12.9 ± 0.5, ΔE = 13.4 ± 0.7, chroma = 14.40 ± 0.51, hue angle = 63.63 ± 2.10°, whiteness index = 32.55 ± 1.31, and browning index = 59.71 ± 5.20. The product was characterized as relatively dark and yellowish-brown, with noticeable browning following thermal processing.

The microwave treatments, particularly 720 W, produced favourable colour characteristics. The research reports that 720 W provided a brighter appearance and higher lightness and whiteness than the cabinet-dried product. At 900 W, the product developed a more vivid reddish-yellow colour and higher browning index, although this was accompanied by other quality compromises.

Thus, microwave drying appears advantageous for maintaining desirable visual characteristics when an appropriate power level is selected.

5. Overall comparison of cabinet and microwave drying

Table 4. Overall Comparison of Cabinet Drying and Microwave Drying of Murrel Fish

Characteristic	Cabinet drying	Microwave drying
Operating condition	60 °C	540–900 W
Pretreatment	10% NaCl, 2 h	10% NaCl, 2 h
Approximate processing time	12 h	28–36 min
Moisture removal	Gradual	Rapid
Drying behaviour	Predominantly falling-rate	Rapid initial moisture removal followed by decline
Drying yield	Not directly comparable in the reported table	32.98–33.56%
Water activity	Not reported in the corresponding cabinet table	0.55–0.58
Protein concentration	61.27%	77.67–85.14%
Rehydration	Higher under optimized cabinet condition than high-power microwave treatments	Decreased from 0.20 to 0.14 as power increased
Antioxidant activity	49.96%	46.44–53.61%
Energy efficiency	Longer processing time	540 W had lowest microwave SEC
Texture	Firm and cohesive	720 W provided balanced texture; 900 W harder
Colour	Darker/yellowish-brown with significant browning	720 W showed favourable brightness/whiteness
Overall assessment	Controlled but slow	Faster and generally superior for fish-powder production

The comparison demonstrates that the principal advantage of microwave drying is processing speed. Cabinet drying required approximately 12 h, whereas microwave drying required less than one hour under all reported microwave conditions. Microwave drying also produced lower moisture and greater apparent protein concentration. However, excessive microwave power reduced rehydration ratio, increased specific energy consumption, reduced antioxidant activity, and increased hardness.

6. Selection of optimum microwave power

Although 900 W provided the shortest drying time and the highest protein concentration, it was not selected as the overall optimum because of its higher specific energy consumption, lower rehydration ratio, lower antioxidant activity, and greater textural hardness.

The 540 W treatment showed the best energy efficiency and highest antioxidant activity but required the longest microwave drying time and produced lower protein concentration than 900 W.

The 720 W treatments provided the best overall compromise. It reduced drying time to approximately 34 min, produced low moisture content, retained acceptable antioxidant activity, provided desirable colour and texture, and maintained better rehydration characteristics than 900 W. The research therefore identifies 720 W as the most practically applicable microwave condition for producing murrel fish powder.

7. Application of microwave-dried fish powder

The optimized microwave-dried fish was converted into powder and subsequently used as an ingredient in value-added fish chips. Fish powder was incorporated at 10%, 15%, and 20%, along with a control without fish powder.

Sensory evaluation was conducted using a 9-point hedonic scale. The average overall acceptability scores were 6.3 for the control, 7.4 for 10% fish powder, 8.0 for 15% fish powder, and 7.2 for 20% fish powder. The 15% fish-powder formulation therefore obtained the highest acceptability.

This result demonstrates that microwave drying can serve not only as a preservation technique but also as a means of generating a functional fish ingredient suitable for incorporation into value-added foods.

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8. Conclusion

The comparative study demonstrated clear differences between conventional cabinet drying and microwave drying of murrel fish (*Channa marulius*). Cabinet drying at the optimized condition of 60 °C with 10% NaCl pretreatment successfully produced a dried fish product with desirable physicochemical characteristics. However, the conventional process required approximately 12 h and exhibited a progressively declining drying rate as moisture became more difficult to remove from the interior of the fish tissue.

Microwave drying substantially accelerated dehydration. Increasing microwave power from 540 to 900 W progressively shortened the drying period, with recorded times of 36, 34, and 28 min, respectively. Microwave treatment also produced fish powders with lower moisture contents and higher apparent protein concentrations than the cabinet-dried product.

Nevertheless, increasing microwave power beyond the optimum was associated with disadvantages. The 900 W treatment had the shortest drying time and highest protein concentration but showed higher specific energy consumption, lower rehydration ratio, lower antioxidant activity, and harder texture. The 540 W treatment provided better energy efficiency and antioxidant retention but required longer drying. Consequently, 720 W was identified as the optimum microwave drying condition, providing the most favourable balance between processing time, energy consumption, nutritional quality, colour, texture, and rehydration.

Overall, microwave drying was superior to cabinet drying for rapid production of high-quality murrel fish powder. The resulting powder was successfully utilized in *a* value-added fish-chip product, with 15% fish-powder incorporation receiving the highest sensory acceptability score. The findings indicate that microwave drying at an appropriately selected power level has considerable potential for efficient murrel-fish processing and value addition.

9. Research significance

The study has practical significance for fish-processing industries because it demonstrates that microwave drying can dramatically reduce processing time compared with conventional cabinet drying. A reduction from approximately 12 h to approximately 34 min at 720 W represents a major opportunity for improving production throughput.

The study also demonstrates the importance of optimizing microwave power rather than simply maximizing power. The results indicate that an intermediate power level can provide a better overall balance between drying efficiency, nutritional characteristics, energy consumption, texture, colour, and rehydration.

For small- and medium-scale fish processors, the development of shelf-stable murrel fish powder could provide an additional route for utilizing seasonal fish availability and producing protein-rich ingredients for convenience foods.

10. Limitations and recommendations for further research

The present study was conducted under the specific experimental conditions reported in the research, and further research is recommended to strengthen the comparative evaluation of cabinet and microwave drying of *Channa marulius*. Future studies should directly measure and compare the total energy consumption of both drying systems at equivalent final moisture contents, investigate lipid oxidation and fatty-acid retention during drying, and determine microbial stability and actual shelf life during storage. Further work should also evaluate different microwave exposure schedules, including pulsed microwave operation, and investigate microwave–hot-air hybrid drying to combine rapid internal heating with improved process control. The effects of fish thickness, sample loading, and microwave distribution on drying uniformity should be studied in greater detail. Development and validation of mathematical drying models for *Channa marulius* under both drying methods would provide useful information for process scale-up. In addition, detailed economic analysis considering equipment cost, energy consumption, labour, processing capacity, and product yield is required to assess industrial feasibility. Finally, sensory evaluation of the dried fish powder itself should be conducted in addition to evaluating its incorporation into value-added products, so that consumer acceptability of the dried powder can be established directly.

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