RESEARCH PAPER

Fiber Fusion Dark Choco Crunch: Formulation, Quality Assessment, and Value Addition Using Agro-Industrial Fruit Waste

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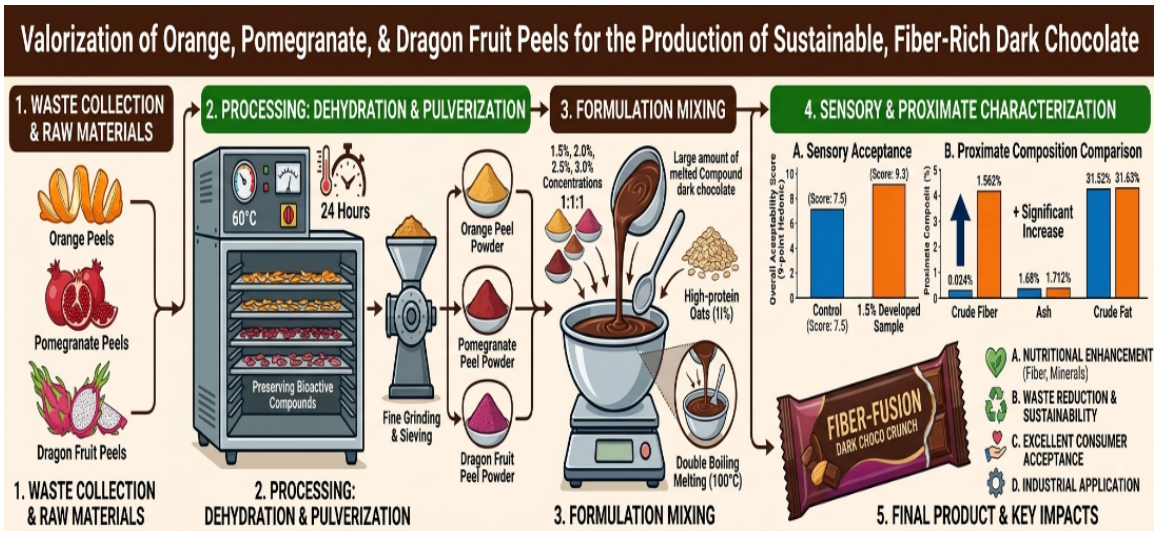
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ABSTRACT

In the modern food industries, large quantities of fruit peels are discarded as waste in the food industry despite being rich sources of dietary fiber, antioxidants, and essential nutrients. The present study aimed to develop a fiber-enriched chocolate by incorporating dehydrated fruit peel powders into a chocolate formulation, thereby improving its nutritional value and promoting sustainable utilization of food processing byproducts. Selected fruit peels (orange ,pomegranate, dragon fruit peels] were thoroughly cleaned, tray dried under controlled conditions to preserve bioactive compounds, and ground into a fine powder and all the peel powders were combined in the ratio of 1:1:1 and then varying concentrations of the combined fruit peel powders were incorporated into chocolate. Sensory evaluation revealed excellent consumer acceptance, with the developed sample having 1.5% fruit peel concentration achieving an overall acceptability score of 9.3 compared to 7.5 for the control. Further Proximate analysis for the optimized developed chocolate showed 1.34± 0.2% moisture, 31.63 ± 0.13% crude fat, 1.712 ± 0.04% ash, and 1.562± 0.13% crude fiber, compared to 1.28% ± 0.21moisture, 31.52± 0.12% crude fat, 1.68± 0.23% ash, and 0.024± 0.21% crude fiber in the control sample, indicating a significant improvement in fiber content. These findings demonstrate that fruit peel powders can be effectively utilized in chocolate production to create a nutritious, acceptable, and value-added functional food product while reducing food waste and supporting sustainable food processing practices.



Keywords: Fibre rich fruit peel, sensory evaluation, dehydration, chocolate

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INTRODUCTION

Globally, fruits are consumed daily and form an important part of the human diet due to their nutritional, physical, chemical, and functional properties [Pathak et al,2015;Abobatta, 2021]. In earlier times, fruits were often expensive and seasonal, making them accessible to only a limited section of the population. However, advancements in agriculture and food processing technologies have increased fruit production and availability, allowing people to consume fruits at affordable prices. India is one of the leading producers of fruits worldwide. Despite their widespread consumption, a significant portion of fruits, particularly the peels, is discarded as waste after consumption and processing. Fruit peel waste (FPW) is abundantly generated by households, agricultural activities, and food processing industries and has attracted attention in recent years for its potential applications, including use as an adsorbent [**Yahia et al,2019**].

Most fruit and vegetable waste is generated in the form of peels, which are often overlooked despite being rich sources of dietary fiber, antioxidants, phenolic compounds, vitamins, and minerals [**Huang et al, 2022**]. Fruits are extensively used in the production of juices, jams, cookies, alcoholic and non-alcoholic beverages, and several other food products. The large-scale processing of fruits generates substantial quantities of peel waste, creating environmental and disposal challenges. However, fruit peels represent an underutilized resource that can be incorporated into food products to enhance their nutritional quality while contributing to waste valorization efforts. In addition to the food sector, fruit peel waste has potential applications in the cosmetic, pharmaceutical, and packaging industries.

Fruit waste is considered a valuable biomass resource because it originates from plant-based materials. Due to its availability and relatively uniform composition, industrial fruit peel waste is an ideal candidate for the production of biomass fuel and various value-added products [**Ganesh et al, 2022**]. Research on fruit waste utilization has increasingly focused on its valorization for the development of functional foods, therapeutic products, and sustainable packaging materials. With the global food processing market continuing to expand, opportunities for converting food waste into valuable products are also increasing. Approximately 42% of food waste is generated at the household level and 38% during food processing, while the remaining portion comes from retail and transportation sectors [**Nirmal et al,2023**]. Nearly half of this waste consists of fruit and vegetable peels. Certain fruits, particularly citrus fruits, generate high levels of peel waste, with almost 50% of the fruit becoming waste after consumption [**Wedamulla et al, 2022**].

The present study focused on the utilization of fruit peel waste, specifically orange peel, pomegranate peel, and dragon fruit peel, for the preparation of a fiber-rich chocolate product. These peels contain significant amounts of carbohydrates, dietary fiber, ash, protein, and small quantities of lipids, making them suitable ingredients for nutritional enrichment [**Chumroenvidhayakul et al, 2023**]. The main objective of this work was to develop a fiber-rich Choco Crunch by incorporating varying concentrations of fruit peel powders along with compound chocolate and oats. The developed products were evaluated through sensory analysis, and the optimized formulation was further analyzed for its proximate and nutritional composition.

MATERIALS AND METHODS

Collection of Samples

Fruit peels were collected from fiber-rich fruits such as orange, dragon fruit, and pomegranate. The peels were carefully separated from the fruit pulp, thoroughly washed to remove dirt and impurities, and subjected to tray drying for 24 hours to reduce their moisture content. After complete drying, the peels were ground into a fine powder and sieved to remove coarse particles and other impurities. The obtained fruit peel powder was stored in airtight containers and used for further product formulation.

Production of Fruit Peel Powder

A tray dryer is a widely used drying equipment in the food, pharmaceutical, and chemical industries for reducing the moisture content of solid materials through controlled temperature and airflow. This process helps improve shelf life, product stability, and safety. In the present study, the collected fruit peels were separated from the pulp, washed thoroughly, and dried in a tray dryer at 60°C for 24 hours as shown in figure 1 to remove excess moisture while preserving their nutritional quality and bioactive compounds [**Marin et al, 2007**]. After drying, the peels were pulverized into a fine powder and stored for subsequent use in the preparation of fiber-rich chocolate.

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Figure 1: Tray drying of fruit peels

Table 1: Formulation of chocolate and control sample

Ingredients	Control	Sample 1	Sample 2	Sample 3
Compound dark chocolate	80 g	80 g	80 g	80 g
Fruit rind powder	—	1.5 g	2.0 g	2.5 g
High-protein oats	18.5 g	18.5 g	18.5 g	18.5 g

PROCESSING STEPS FOR PREPARATION OF CHOCOLATE

1. Processing of Fruit Peel Powder

The dried fruit peels were ground into a fine powder using a grinder. The obtained powder was then sieved to remove coarse particles and ensure uniform particle size. The fine fruit peel powder was collected and stored in airtight containers until further use in chocolate preparation as shown in figure 2.



Figure 2 :Fruit peels powders

2. Mixing Ratio of Ingredients

The formulation of chocolate plays an important role in achieving the desired texture, flavor, and overall acceptability of the product. The chocolate formulation used in this study consisted of 80% compound dark chocolate, 18.5% high-protein oats, and 1.5% fruit peel powder. These ingredients were carefully measured and blended to obtain a uniform mixture as shown in table 1.

3. Melting of Compound Dark Chocolate and Mixing of Dry Ingredients

The compound dark chocolate was melted using the double-boiling method to ensure uniform melting and prevent scorching. After complete melting, the pre-weighed dry ingredients, including high-protein oats and fruit peel powder, were gradually added and mixed thoroughly to achieve a homogeneous blend suitable for chocolate moulding as shown in figure 3.

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Figure 3: Melting of chocolate using double boiling method

4. Addition of Dry Ingredients

The fruit peel powder and high-protein oats were added to the melted compound dark chocolate (CDC). The mixture was stirred thoroughly to ensure even distribution of the ingredients and to obtain a uniform chocolate mixture as shown in figure 4.

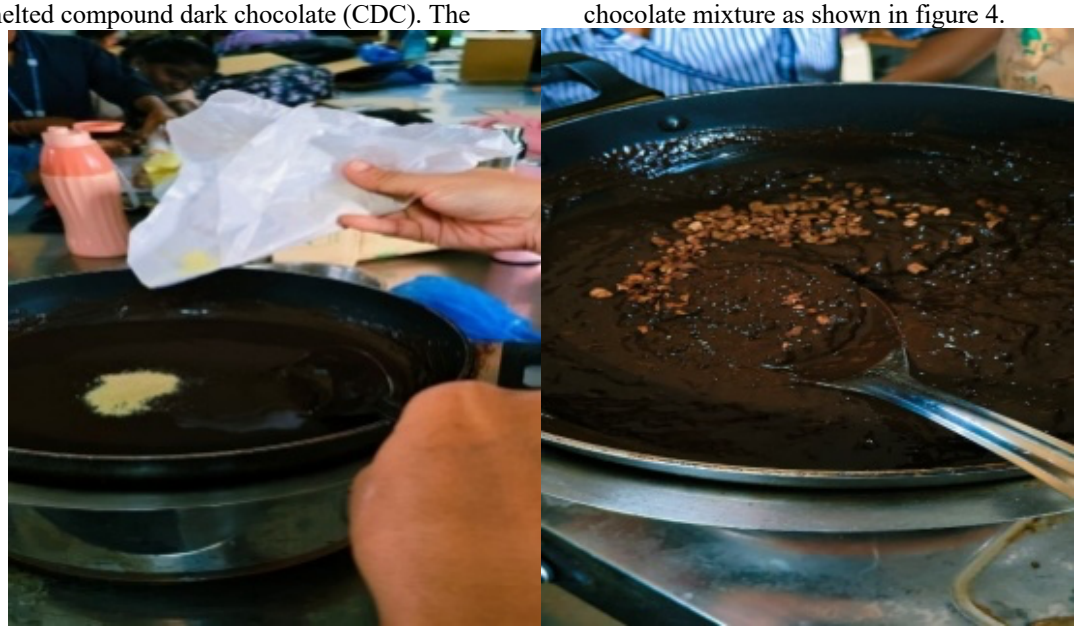


Figure 4: Addition of mixture fruit peel powders and oats

5. Transfer of Mixture into Moulds

After achieving a homogeneous mixture, the chocolate mass was poured evenly into moulds. The filled moulds were refrigerated for 3–4 hours to allow proper setting of the chocolate. Once hardened, the chocolates were carefully demoulded, packed appropriately, and stored under suitable conditions until further analysis. The chocolate preparation was shown in figure 5.

Preparation of chocolate

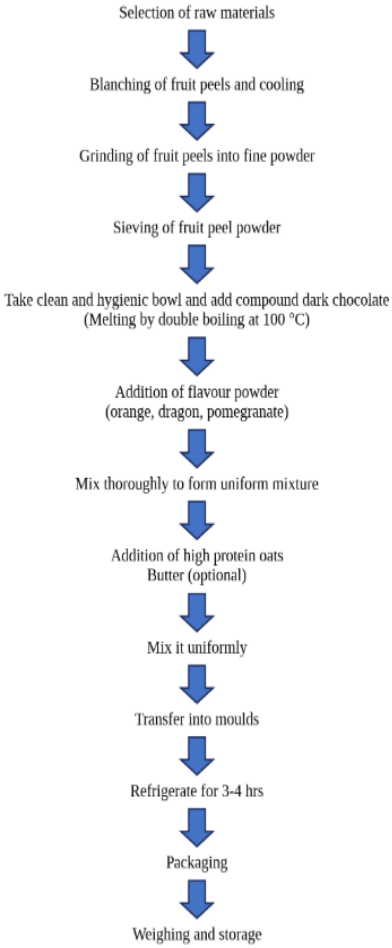


Figure: 5 Process of Preparation of chocolate

SENSORY ANALYSIS

Sensory analysis was carried through 9 scale hedonic scale with 30 semi trained panel as shown in table 2 the optimized sample showed highest overall acceptability and optimized sample was carried out to proximate analysis. After sensory analysis the sample having highest overall acceptable the results were tabulated in the table format of table 3 and were further analysed for proximate analysis along with control sample**.**

Table 2: 9 point hedonic scale performances for sensory analysis

Sample	Overall acceptability
Like extremely 9	
Like very much 8	
Like moderately 7	
Like slightly 6	
Neither like or dislike 5	
Dislike slightly 4	
Dislike moderately 3	
Dislike very much 2	
Dislike extremely 1	

Table 3: Sensory marks sheet

Sample	Appearance	Colour	Texture	Aroma	Taste	Overall

Control						
S1						
S2						
S3						

PROXIMATRE ANALYSIS

The proximate analysis was performed for control and optimized sample, analysed for Moisture content, Crude fiber ,ash content ,crude fat and the results were tabulated in the format of table 4.

ANALYSIS OF MOISTURE CONTENT:

Moisture Content (%) = (Initial Weight – Final Weight) ÷ Initial Weight × 100

ANALYSIS OF CRUDE FIBER :

Crude Fiber (%) = Weight of Dried Residue –Weight of Ash÷ Weight of Sample × 100

ANALYSIS OF ASH CONTENT :

Ash Content (%) =Weight of Ash ÷ Weight of Sample × 100

ANALYSIS OF CRUDE FAT :

Crude Fat (%) = Weight of Extracted Fat ÷ Weight of Sample × 100

Table 4 : Proximate analysis

S.no	Parameters	Control	Sample
1	**Moisture (%)**		
2	**Crude fat (%)**		
3	**Ash (%)**		
4	**Crude fiber (%)**		

RESULTS AND DISCUSSION

Drying Characteristics of Fruit Peels

The drying characteristics of orange, pomegranate, and dragon fruit peels were studied during tray drying at 60°C. A gradual reduction in weight was observed throughout the drying process, indicating effective moisture removal from the samples. The initial weights recorded during the first hour were 135.11 g for orange peel, 142.51 g for pomegranate peel, and 153.58 g for dragon fruit peel. A rapid decrease in weight occurred during the initial hours of drying, followed by a slower rate of moisture loss as drying progressed. By the sixth and seventh hours, the samples reached nearly constant weights of 115.36 g, 126.26 g, and 126.97 g, respectively, indicating that equilibrium moisture content had been achieved as shown in table 5 and figure 6.

Table 5 : Drying kinetics of fruit peels

Time Interval	Sample 1 (Orange)	Sample 2 (Pomegranate)	Sample 3 (Dragon Fruit)
1 hour	135.11 g	142.51 g	153.58 g
2 hours	116.01 g	129.77 g	135.45 g
3 hours	115.77 g	127.01 g	128.35 g
4 hours	115.60 g	126.73 g	127.42 g
5 hours	115.54 g	126.54 g	127.19 g
6 hours	115.40 g	126.33 g	127.04 g
7 hours	115.36 g	126.26 g	126.97 g

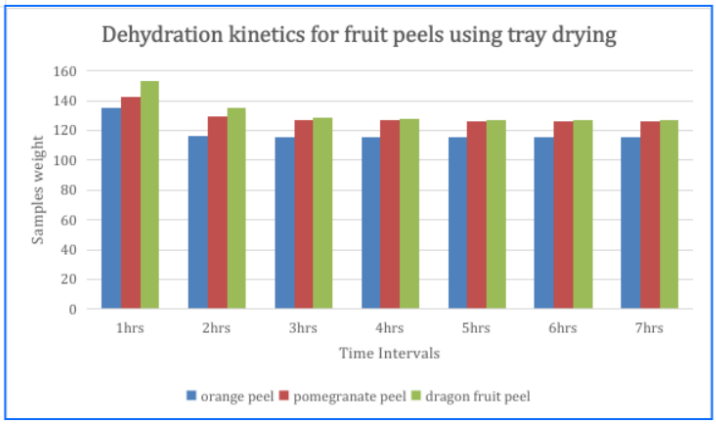


Figure 6 : Dehydration kinetics for fruit peels using tray drying

Figure 6 : Dehydration kinetics for fruit peels using tray drying

The rapid moisture loss observed during the early stages can be attributed to the evaporation of free surface moisture, whereas the slower drying phase corresponds to the removal of bound moisture from the peel tissues. Attaining a constant weight confirms adequate drying, which is essential for reducing water activity, preventing microbial growth, and improving shelf stability. Furthermore, proper dehydration facilitates efficient grinding and the production of a uniform peel powder suitable for incorporation into food products. The drying temperature of 60°C was found to be effective in preserving the structural quality and bioactive compounds of the peels, making them suitable for functional food applications.

SENSORY ANALYSIS



Figure 7: Sensory Evaluation of Finished product Fiber Fusion Dark Choco Crunch

The sensory evaluation of the developed Fiber Fusion Dark Choco Crunch whose finished product was shown in figure 7, was conducted using a 9-point hedonic scale to determine consumer acceptability based on appearance, colour, texture, aroma, taste, and overall acceptability. The results revealed that the peel-enriched chocolate received higher scores than the control sample for all sensory attributes. The control sample scored 8 for appearance, colour, texture, and aroma, 7 for taste, and 7.5 for overall acceptability as shown in table 6. In comparison, the developed sample achieved scores of 9 for appearance, colour, texture, aroma, and taste, resulting in an overall acceptability score of 9 as shown in figure 8. The enhanced sensory quality of the developed product may be attributed to the incorporation of fruit peel powder and high-protein oats, which contributed to improved crunchiness, flavour, and mouthfeel without causing bitterness or any undesirable aftertaste. Furthermore, the overall acceptability index of the developed sample was 85%, compared to 75% for the control sample. These findings indicate that the incorporation of fruit peel powder not only improved the nutritional quality of the chocolate but also enhanced its sensory appeal, making it highly acceptable to consumers sensory quality.

Table 6 : Scores for different attributes of samples

Sample	Appearance	Colour	Texture	Aroma	Taste	Overall
Control	8.0	8.0	8.0	8.0	7.0	7.5
S1	9.5	9.5	9.5	9.5	9.5	9.5
S2	8.8	8.7	8.0	8.0	7.0	8.1
S3	8.5	8.5	8.0	7.9	6.5	7.8

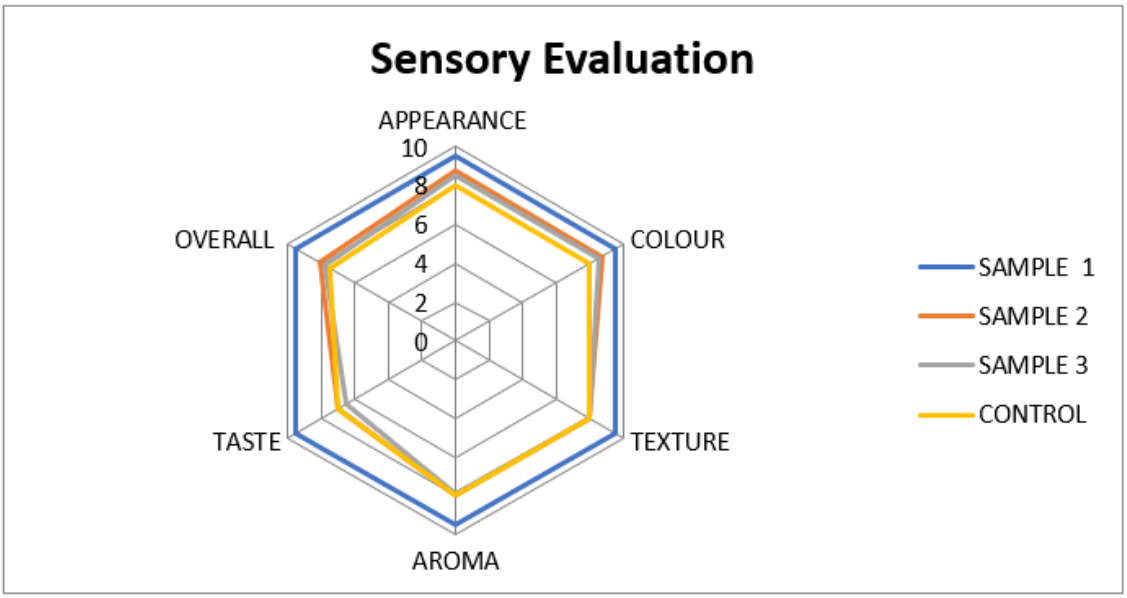


Figure 8: Sensory analysis graph

PROXIMATE ANALYSIS

The rapid moisture loss observed during the early stages can be attributed to the evaporation of free surface moisture, whereas the slower drying phase corresponds to the removal of bound moisture from the peel tissues. Attaining a constant weight confirms adequate drying, which is essential for reducing water activity, preventing microbial growth, and improving shelf stability. Furthermore, proper dehydration facilitates efficient grinding and the production of a uniform peel powder suitable for incorporation into food products. The drying temperature of 60°C was found to be effective in preserving the structural quality and bioactive compounds of the peels, making them suitable for functional food applications.

PROXIMATE COMPOSITION OF DEVELOPED CHCOLATE

Based on preliminary trials and sensory evaluation results, Sample 1 was selected as the optimized formulation for the development of Fiber Fusion Dark Choco Crunch. The proximate composition of the developed chocolate was compared with that of the control sample to evaluate the nutritional impact of fruit peel powder incorporation as shown in table 8.

DETERMINATION OF MOISTURE CONTENT

The moisture content of the developed chocolate sample was 1.34%, which was slightly higher than that of the control sample (1.28%). However, the difference was minimal and remained within acceptable limits for chocolate products. The low moisture content indicates good shelf stability and confirms that the incorporation of fruit peel powder did not adversely affect the product's quality or storage characteristics. It also reflects the effectiveness of the drying process applied to the fruit peels before their incorporation into the chocolate formulation.

DETERMINATION OF CRUDE FAT

The crude fat content increased marginally from 31.52% in the control sample to 31.63 ± 0.13% in the developed sample. Since compound dark chocolate serves as the primary source of fat in the formulation, the slight increase may be attributed to interactions between the fruit peel powder, oats, and the cocoa fat matrix. The variation was minimal and did not negatively affect the texture, flavour, or overall quality of the chocolate.

Table 8 : Proximate analysis results

S.no	Parameters	Control	Sample
1	Moisture(%)	1.28±0.21	1.34±0.2

2	Crude fat(%)	31.52±0.12	31.63±0.13
3	Ash(%)	1.68±0.23	1.712±0.04
4	Crude fiber(%)	0.024±0.21	1.562±0.13

DETERMINATION OF ASH CONTENT

Ash content represents the total mineral content present in a food product. The ash content of the developed chocolate increased slightly from 1.68% in the control sample to 1.712 ± 0.04%. This increase can be attributed to the mineral contribution of the fruit peel powder, which contains appreciable amounts of essential minerals. The result suggests that the incorporation of fruit peel powder improved the micronutrient content of the developed chocolate.

DETERMINATION OF CRUDE FIBER

A substantial increase in crude fiber content was observed following the incorporation of fruit peel powder. The control sample contained only 0.024% crude fiber, whereas the developed chocolate contained 0.562% crude fiber. This significant improvement demonstrates the effectiveness of fruit peel powder as a functional ingredient for fiber enrichment.

Orange peel, pomegranate peel, and dragon fruit peel are naturally rich sources of dietary fiber, containing approximately 64.3%, 60.1%, and 56.9% fiber, respectively. Even at a relatively low inclusion level of 1.5%, the fruit peel powder significantly enhanced the fiber content of the chocolate. The increased fiber level improves the nutritional quality of the product and supports the development of functional confectionery products with added health benefits presents the proximate composition and sensory evaluation results of the control and developed chocolate samples. The improved texture observed in the developed sample may be attributed to the structural and binding properties of oats and fruit peel powder, which contributed to a desirable crunch and enhanced mouthfeel. Furthermore, the incorporation of fruit peel powder did not result in bitterness or any undesirable off-flavours, suggesting that the drying and processing methods were effective in preserving sensory quality while minimizing potential defects [**Negi et al,2003**].

The overall acceptability index of the developed sample was 85%, compared to 75% for the control sample. These findings indicate that fiber enrichment not only maintained the sensory quality of the chocolate but also enhanced consumer preference. The developed product retained desirable melting characteristics while offering improved texture and flavour complexity.

FUNCTIONAL AND NUTRITIONAL IMPLICATIONS

As a functional ingredient in chocolate production, the significant increase in dietary fiber content, along with a slight improvement in mineral content, highlights the nutritional advantages of incorporating fruit peel powder into confectionery products. From a technological perspective, the optimized level of peel powder addition did not negatively affect moisture content, fat content, product stability, or sensory attributes.

The inclusion of high-protein oats together with antioxidant-rich dark chocolate further enhanced the functional value of the product. The combination of dietary fiber, antioxidants, and other bioactive compounds may provide potential health benefits, including improved digestive health and increased satiety.

DISCUSSION

The present study demonstrates the potential of agro-industrial waste valorization in the development of functional food products. A comparison between control and sample of fruit peel powder-enriched Fiber Fusion Dark Choco Crunch highlights the successful utilization of food processing by-products for value-added product development.

The fruit peel-enriched chocolate developed in the present study demonstrated a substantial improvement in nutritional quality, particularly in crude fiber content, which increased from 0.024% in the control sample to 0.562% in the developed sample. Ash content also increased slightly from 1.68% to 1.712%, indicating enhanced mineral contribution. At the same time, moisture content (1.34%) and crude fat content (31.63%) remained within acceptable limits. Sensory evaluation results revealed excellent consumer acceptance, with the developed sample achieving an overall acceptability score of 9 compared to 7.5 for the control sample. Improvements were observed across all sensory attributes, including appearance, colour, texture, aroma, and taste. It was also found that for the present study the related references are very few proving the uniqueness of the work.

The study also highlights the importance of sustainable food processing practices. Fruit peels, which are commonly discarded as agricultural waste, represent valuable sources of dietary fiber, antioxidants, and bioactive compounds. Their incorporation into chocolate supports waste reduction and aligns with the principles of the circular economy.

This approach addresses two major global challenges:

• Food waste management

• Growing consumer demand for functional foods

By converting fruit peel waste into a shelf-stable powder and incorporating it into a widely accepted confectionery product, the study presents a practical and scalable strategy for industrial application. The use of tray drying offers an economical and feasible processing method for small- and medium-scale food industries.

Furthermore, the combination of fruit peel powder, oats, and dark chocolate enhances both the nutritional and sensory qualities of the final product, making it suitable for consumers of different age groups seeking

healthier snack alternatives. The increase in dietary fiber without substantial changes in fat and moisture content demonstrates successful formulation optimization. Additionally, the positive sensory evaluation results confirm strong consumer acceptance, which is a critical factor for the commercial success of the product.

CONCLUSION

The present study successfully demonstrated the utilization of fruit processing by-products for the development of a value-added functional food product. Fruit peels from orange, pomegranate, and dragon fruit were effectively processed through washing, drying, and grinding to produce a fiber-rich powder suitable for chocolate fortification. The incorporation of fruit peel powder, along with high-protein oats and dark chocolate, resulted in the development of Fiber Fusion Dark Choco Crunch, a nutritionally enhanced confectionery product with improved dietary fiber content and excellent sensory acceptability. The developed chocolate showed significant improvement in crude fiber content while maintaining desirable moisture, fat, and sensory characteristics. Furthermore, the study highlights the potential of converting fruit peel waste into a valuable food ingredient, thereby supporting sustainable food processing and waste reduction practices. Overall, the developed product meets the increasing consumer demand for healthier snack options and demonstrates the feasibility of utilizing fruit processing waste in functional food development.

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