Vol. 5 No. 1 (2026)

Pakistan Journal of Medical & Cardiological Review

https://pakjmcr.com/index.php/1/about

Online ISSN 3007-2387

Print ISSN 3007-2379

Development of *Fagonia* Based Nutraceutical Crackers For Potential Hepatoprotective Benefits

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Keywords: Anti-inflammatory, Anti-oxidant, Crackers, *Fagonia indica*

Received on 05 Feb 2026
Accepted on 08 Mar 2026
Published on 16Mar 2026

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Abstract

The present study was aimed to develop nutraceutical crackers enriched with *Fagonia* to explore their hepatoprotective benefits. Hepatoprotective benefits include antioxidant, anti-inflammatory and membrane stabilizing effects. Hepatic steatosis (accumulation of fat) is a key pathological feature of non-alcoholic fatty liver disease (NAFLD), and *Fagonia* is known for its therapeutic properties, including anti-inflammatory, antioxidant, membrane stabilizing and metabolic benefits. *Fagonia* was incorporated in nutraceutical crackers to make them a source to improve liver health conditions. The formulated nutraceutical crackers had undergone nutritional analysis including iron and zinc content and total phenolic content, along with DPPH radical scavenging activity to assess antioxidant capacity. After the development of a product its analysis were conducted. Antioxidant analysis revealed a marked increase in radical scavenging activity and total phenolic content with increasing *Fagonia indica* concentration. This confirmed the presence of potent phytochemicals that contribute to oxidative stress reduction. The outcome suggested that crackers prepared with optimum levels of *Fagonia* powder contained better sensory quality and greatly enhanced nutritional qualities than the traditional crackers. This research emphasizes the viability of using herbs in mainstream foods which reduce liver related diseases and positively impact liver health.

Introduction

The liver is a vital organ responsible for metabolism, detoxification of harmful substances, bile production, and immune regulation. It processes both nutrients and

xenobiotics, making it particularly vulnerable to injury from infections, toxins, drugs, alcohol, and metabolic disorders. Damage to the liver can lead to impaired liver function, inflammation, fibrosis, or even liver failure. Chronic liver diseases are a significant global health problem, affecting millions of people worldwide and contributing to high morbidity and mortality rates (Devarbhavi et al., 2023). Another reason for hepatocellular death is "lipid peroxidation". Cell membranes of hepatocytes are mostly made of lipid (fats). When these fatty components are attacked by ROS, hepatocytes susceptibility of getting dysfunctional is increased. If the inflammation caused by oxidative stress in left untreated, it may develop into hepatitis, fatty liver disease or cirrhosis (Li et al., 2023). Inflammation is the also the major cause of worsening of liver diseases. When the liver undergoes oxidative stress, then, immune system gets active for giving a response. Pro-inflammatory cytokines are released by immune cells of liver for instance, kupffer cells, neutrophils or lymphocytes. If the production of pro-inflammatory cytokines exceed optimum level than it can be hazardous for hepatocytes. tumor necrosis factor-alpha (TNF-α), interleukin-1β (IL-1β), and interleukin-6 (IL-6) are those Pro-inflammatory cytokines which can cause an injury to liver and leads to a prolonged inflammation (Del Campo et al., 2018). Non-alcoholic Steatohepatitis is the liver disease, in which prolonged inflammation becomes the reason for scarring of a tissue (fibrosis). When it's left untreated, it leads to acute liver damage (Friedman, 2008). Oxidative phosphorylation and oxidation of fatty acids are the processes through which mitochondria produce energy. In case of mitochondrial dysfunction, electrons are leaked as a result of inefficient electron transport chain and another problematic thing is the excessive production of reactive oxygen species (ROS). Mitochondrial protein, DNA and lipids are damaged as a result of increased ROS. This cause disruption in normal mitochondrial activity, that would further become a cause of disturbance of cellular homeostasis in liver. Antioxidants are crucial for protecting hepatocytes against oxidative stress as these are potentially able to neutralize reactive oxygen species ROS. When oxidative stress is countered and controlled then cellular balance is also maintained. That's how normal and regular function of liver is maintained by antioxidants. In today's era, natural health products are considered more sustainable and easy to use in comparison with synthetic drugs. Polyphenols, flavonoids, vitamins, minerals and antioxidants play an important role in regulation of metabolic processes and reduction of oxidative stress. Thus, they contribute in prevention of diseases and promotion of overall health of human body (Mohammadian et al., 2024). Nutraceuticals having plant compounds rich in antioxidants are explored on wider extent to know about the hepatoprotective benefits. Plant compounds are generally known as phytochemicals that have shown the potential to reduce oxidative stress and stop inflammatory responses. They have also shown the ability to save hepatocytes from metabolic disturbances and toxins. So, the use of antioxidants derived from plant sources in development of nutraceuticals for protection of hepatocytes can be a viable approach to maintain overall liver health (Li et al., 2023). *Fagonia* is a medicinal plant genus belonging to the family **Zygophyllaceae**. Several species of *Fagonia*, including *Fagonia indica*, *Fagonia cretica*, and *Fagonia arabica*, have been traditionally used for their therapeutic properties. Due to its long-standing use in traditional medicine and its broad biological importance, *Fagonia* has become a plant of growing scientific interest in the field of natural product research and nutraceutical development (Iftikhar et al., 2022). Phytochemical studies have revealed that *Fagonia* contains a variety of important bioactive compounds, including flavonoids, saponins, alkaloids, tannins, terpenoids, and phenolic compounds. These phytochemicals are known to possess antioxidant, anti-inflammatory, antimicrobial, and protective effects. Among them, flavonoids and phenolic compounds are especially important because they help neutralize free radicals and reduce oxidative stress in the body. Since oxidative stress is one of the major contributing factors in the development of chronic

diseases, including liver disorders, the phytochemical richness of *Fagonia* makes it a promising candidate for use in functional foods and nutraceutical formulations (Sharif et al., 2026). Recent scientific investigations have further highlighted the medicinal value of *Fagonia* by demonstrating its antioxidant and anti-inflammatory potential in experimental studies. These biological activities are highly relevant to liver health because oxidative stress and inflammation are considered major mechanisms involved in liver injury. Plant materials capable of reducing these harmful processes are often regarded as useful hepatoprotective agents. Therefore, *Fagonia* may have the potential to support liver function by helping to minimize cellular damage and strengthen the body's natural defense system (Arman et al., 2022). The hepatoprotective potential of medicinal plants is often linked to the presence of phytochemicals such as flavonoids, phenolic acids, saponins, tannins, and terpenoids. These compounds are known to scavenge free radicals, reduce lipid peroxidation, and modulate cellular signaling pathways involved in inflammation and apoptosis. Scientific studies have shown that antioxidant-rich plant extracts may improve liver enzyme levels, reduce tissue damage, and support normal hepatic function in experimental models of liver injury. Therefore, the presence of such bioactive constituents provides an important scientific basis for selecting medicinal plants for nutraceutical and functional food development. Crackers are considered a suitable food vehicle for the development of nutraceutical products because they are widely consumed, convenient, shelf-stable, and easy to formulate (Guiné & Florença, 2024)**.** Nutraceutical formulations incorporating medicinal plants, such as *Fagonia*, offer significant potential for liver health management. Due to their rich content of antioxidants and anti-inflammatory compounds, such formulations can help in reducing oxidative stress, preventing lipid accumulation, and inhibiting inflammatory pathways. *Fagonia* is known for its antioxidant, anti-inflammatory, and wound-healing properties. Phytochemical investigations revealed that *Fagonia* contains important bioactive compounds such as flavonoids, alkaloids, tannins, and saponins, which contribute to its hepatoprotective potential by reducing oxidative stress and stabilizing cellular membranes (Khan et al., 2022).

Materials and Methodology

The recent study was conducted at Riphah International University Department of Human Nutrition and Dietetics in Faisalabad. The work included the development of *Fagonia* based nutraceutical crackers for potential hepatoprotective benefits. A comparative research was conducted to determine the physiochemical, mineral activity, nutritional analysis and sensory analysis of *Fagonia indica*. *Fagonia* was purchased from the local market to make *Fagonia* based nutraceutical crackers. The aerial parts of *Fagonia indica* were cleaned, washed with tap and distilled water, and shade dried at 25–30 °C for 7–10 days (Azam et al., 2018). Then dried parts were cut, ground in a stainless steel grinder (Ranker GMO-1), and strained through a 250 µm mesh to obtain uniform powder. Coarse residues were re-milled (Folkard & Grand, 2001). The final powder was stored in airtight amber bags at 4–8 °C to maintain phytochemical stability. That ensured preservation of *Fagonia*'s hepatoprotective, antioxidant, and anti-inflammatory compounds (Khan et al., 2018).

Treatment Plans

Treatment	Flour (%)	*Fagonia* powder (%)
T_0	100	0
T_1	90	10
T_2	75	25
T_3	60	40

Then crackers were prepared by using *Fagonia* powder. Then for the dough making,

1/2 cup of flour was used with 2 and 1/2 tsp of oil, 2 tbsp + 1tsp of water, a large pinch of baking soda (1/8 tsp), a large pinch of salt (1/8 tsp), 1/4 tsp of sugar and 1 + 1/4 tsp of *Fagonia* powder were used. The mixture was mixed in a bowl to ensure all the *Fagonia* powder is incorporated in the flour. Then the dough was rolled very thin to get crackers. Then these crackers were baked for 12 minutes.

The nutraceutical crackers were analyzed for moisture content, ash content, crude protein, crude fat, crude fiber by following the method of (AOAC, 2016). The iron was determined by using a spectrophotometer according to the method using AOAC (2016). The sample of 2g was weighed in a crucible. Then sample was placed in muffle furnace at 550-600ºC to reduce it into the light gray ash (after burning for approximately 2 hours). It was done to ensure the removal of organic matter from flour and *Fagonia*. Then the obtained ash was dissolved in minute quantity of HCl solution and then it was gently warmed. Then Hydroxylamine Hydrochloride was added to the solution to ensure that all iron was present in Ferrous state. Then pH was adjusted to approximately 3.5 to 4.5 by using acetate buffer for color reaction to be stable. Then 1,10-Phenanthroline was added. Iron formed a bright orange-red complex with these reagents. Then absorbance of the solution was measured using a spectrophotometer at a wavelength of 510nm.

The zinc was determined by using an Atomic Absorption Spectrometry according to the method using AOAC (2016). The sample of 2g was weighed in a crucible. Then sample was placed in muffle furnace, then gradually the temperature was increased to 450ºC to reduce it into the light gray ash (after burning for approximately 6-16 hours). It was done to ensure the removal of organic matter from flour and *Fagonia*. Then the obtained ash was dissolved in 5ml of HCl solution and then it was evaporated to dryness on a hot plate. Then the residue was redissolved in 10ml of 0.1M HNO_3. The Atomic Absorption Spectrometer was set to 213.9 nm, the primary resonance line for zinc. The zinc concentration in the sample was determined by comparing its absorbance to a calibration curve made using recognized zinc standards.

The method used for the determination of total phenolic content was Folic Ciocalteu Assay. 1g of crushed cracker was mixed with 80% methanol to extract antioxidants. Then this extract was combined with Folin Ciocalteu reagent and sodium carbonate. Then blue color was developed in 90 minutes. Then absorbance was measured at 765nm using a spectrophotometer and concentration was determined by using a Gallic acid standard curve.

For measuring radical scavenging activity by DPPH, cracker extract was mixed with purple colored DPPH methanolic solution and incubated in the dark for 30 minutes. When the antioxidants in the *Fagonia* neutralized the radicals, the solution changes from purple to yellow. The prepared *Fagonia* based nutraceutical crackers were estimated for their nutritional value, physiochemical characteristics, mineral activity, sensory evaluation and storage stability when stored at ambient temperature for 30 days using Hedonic scale.

The obtained data from the study was finalized and outcomes from contemporary research were statistically analyzed by applying complete randomized design (CRD) for further analysis according to the protocol defined by (Montgomery, 2018).

Results and Discussions

The development of crackers fortified with *Fagonia indica* powder represents a promising approach to producing a functional food with potential hepatoprotective propertiesIncorporating *Fagonia indica* powder into crackers provides a convenient, acceptable, and shelf-stable food product that can serve as a vehicle for delivering these beneficial phytochemicals as part of the daily diet. Such functional crackers may contribute to the prevention and management of liver disorders by enhancing the body's antioxidant defense system, reducing hepatic injury, and promoting overall liver function. Furthermore, the use of *Fagonia indica* in bakery products increases

the nutritional and therapeutic value of conventional snacks, making them a practical option for health-conscious consumers seeking dietary strategies to support liver health. Therefore, *Fagonia indica*-enriched crackers have significant potential as a novel functional food for hepatoprotection and overall wellness.

Table 1 *Composition Analysis of Fagonia based nutraceutical crackers for potential hepatoprotective benefits*

Treatments	Proximate Analysis				
	Moisture	Ash	Fat	Fiber	Protein
T_0	3.00 ± 0.02^{c}	1.85 ± 0.03^{c}	6.20 ± 0.04^{c}	2.40 ± 0.03^{c}	11.50 ± 0.05^{c}
T_1	3.50 ± 0.03^{bc}	2.10 ± 0.04^{bc}	6.45 ± 0.04^{bc}	3.10 ± 0.04^{bc}	12.10 ± 0.04^{b}
T_2	4.20 ± 0.04^{ab}	2.45 ± 0.05^{ab}	6.78 ± 0.05^{ab}	4.25 ± 0.05^{ab}	12.85 ± 0.05^{ab}
T_3	5.00 ± 0.05^{a}	2.80 ± 0.05^{a}	7.10 ± 0.05^{a}	5.60 ± 0.05^{a}	13.60 ± 0.05^{a}

The moisture content in *Fagonia* based nutraceutical crackers was analyzed and recorded as 3.00 ± 0.02, 3.50 ± 0.03, 4.20 ± 0.04, 5.00 ± 0.05% respectively, across different sample batches. The increase in moisture content with increasing incorporation of *Fagonia indica* can be explained by its rich fiber composition and strong water-holding ability. Dietary fiber absorbs and retains water within the dough system, which leads to slightly higher remaining moisture after baking. Nevertheless, because crackers are baked at high temperatures and formed into thin sheets, most of the moisture is removed, keeping the final values within the acceptable low range. The minor differences among treatments may be due to uneven distribution of fiber, variations in moisture loss during baking, and small differences due to sample handling and analytical conditions. Moisture content of fiber-enriched crackers typically ranges between Moisture content reported for fiber and plant based cracker formulations ranges from 5.12 ± 0.2% to 5.23 ± 0.1% (Abdel-Aal et al., 2023).

The ash content of samples was recorded as 1.85 ± 0.03, 2.10 ± 0.04, 2.45 ± 0.05, 2.80 ± 0.05% respectively. It showed that the ash content was increased with rise in *Fagonia indica* powder incorporation in crackers. It showed that added ingredient "*Fagonia* powder" was rich in minerals. Due to this, total inorganic residue was enhanced in crackers. Similar values have been reported in plant-based and herbal fortified bakery products, where ash content increased due to the higher mineral composition of botanical ingredients. The reported value of ash content is 2.72 ± 0.04% according to (Sharma et al., 2022) is aligned with our findings and supports the statement that when plant based ingredients are added then mineral content is increased and this results in increased value of ash content. Another value 2.58 ± 0.05% according to the study conducted by (Ahmed et al., 2021) reinforces that plant powders cause elevated ash content. Despite this increase, all values remained within acceptable limits for crackers, indicating that incorporation of *Fagonia indica* enhances mineral content without compromising product quality.

the crude protein content of *Fagonia* based nutraceutical crackers was analyzed across different treatments to assess the effect of incorporating *Fagonia* powder in nutraceutical crackers. The crude protein was analyzed and recorded across different samples as 11.50 ± 0.05, 12.10 ± 0.04, 12.85 ± 0.05, 13.60 ± 0.05% respectively. Protein is beneficial for digestion as it gives you the feeling of fullness for longer time and provides satiety. The values of crude protein were observed getting increased when amount of *Fagonia indica* was increased. It was due to the fact that *Fagonia* powder carried the plan based protein and whole wheat protein was also present in crackers due to the use of whole wheat for making dough of crackers.

Crude fiber is an important dietary component, especially when considering foods that support liver health. It plays an important role in lowering inflammation, and improving metabolic function, particularly in the prevention and management of Non-Alcoholic Fatty Liver Disease (NAFLD). High fiber intake can potentially lower the risk of NAFLD and reduced mortality in patients with cirrhosis. In this study, the crude fiber content of *Fagonia* based nutraceutical crackers was analyzed and recorded. The values of crude fiber analyzed and recorded across different sample batches are 2.40 ± 0.03, 3.10 ± 0.04, 4.25 ± 0.05, 5.60 ± 0.05% respectively. In these values, an increase was observed with the addition of *Fagonia indica* powder incorporation in crackers. It showed that adding *Fagonia indica* made the crackers more nutritious and beneficial for health, especially as a source of dietary fiber. A study reported the value of crude fiber 4.35 ± 0.05% by (Putri et al. 2023).

The crude fat was analyzed and recorded across different sample batches as 6.20 ± 0.04, 6.45 ± 0.04, 6.78 ± 0.05, 7.10 ± 0.05 % respectively. It was observed that the highest value of crude fat was recorded in last treatment sample having more concentration of *Fagonia* powder. It showed that addition of more plant based powder can cause increase in fat but this helped ingredients to combine in dough.

Table 2 *Effect of storage and treatment on Iron contents ± SD of Fagonia based nutraceutical crackers*

Treatments	0	15	30	Means
T_0	3.10 ± 0.5^{d}	3.40 ± 0.5^{d}	3.70 ± 0.5^{d}	3.40 ± 0.55^{d}
T_1	3.65 ± 0.5^{c}	3.95 ± 0.6^{c}	4.25 ± 0.6^{c}	3.95 ± 0.60^{c}
T_2	4.40 ± 0.5^{b}	4.70 ± 0.6^{b}	5.00 ± 0.6^{b}	4.70 ± 0.62^{b}
T_3	5.30 ± 0.6^{a}	5.60 ± 0.6^{a}	5.90 ± 0.7^{a}	5.60 ± 0.66^{a}
Overall Mean	4.11 ± 0.57^{c}	4.41 ± 0.61^{b}	4.71 ± 0.64^{a}	

The iron content was analyzed. The control sample are made from 100% whole wheat flour which doesn't include any concentration of *Fagonia* powder has mean value of 3.40 ± 0.55%, after that for T_1: 3.95 ± 0.60, T_2: 4.70 ± 0.62, T_3: 5.60 ± 0.66. Both whole wheat flour and *Fagonia indica* powder contribute to the iron content of the developed nutraceutical crackers. Whole wheat provides a baseline level of iron, while the incorporation of *Fagonia indica*, being a mineral-rich medicinal plant, enhances the overall iron concentration. Increased iron intake through such fortified products may help in preventing iron deficiency anemia, improving oxygen transport, supporting cognitive function, and strengthening immunity. Therefore, incorporation of *Fagonia indica* in nutraceutical crackers offers significant nutritional advantages in terms of iron enrichment, which can offer hepatoprotective benefits (Ali & Khan, 2021).

Table 3 *Effect of storage and treatment on Zinc contents ± SD of Fagonia based nutraceutical crackers*

Treatments	0	15	30	Means
T_0	1.60 ± 0.1^{d}	2.20 ± 0.05^{d}	2.80 ± 0.12^{d}	2.20 ± 0.52^{d}
T_1	1.95 ± 0.1^{c}	2.60 ± 0.06^{c}	3.25 ± 0.10^{c}	2.60 ± 0.58^{c}
T_2	2.35 ± 0.1^{b}	3.10 ± 0.07^{b}	3.85 ± 0.1^{b}	3.10 ± 0.62^{b}
T_3	3.00 ± 0.1^{a}	3.80 ± 0.08^{a}	4.60 ± 0.13^{a}	3.80 ± 0.66^{a}
Overall Mean	2.23 ± 0.1^{c}	2.93 ± 0.07^{b}	3.63 ± 0.12^{a}	

The zinc content was analyzed. The control sample was made from 100% whole wheat flour which doesn't include any concentration of *Fagonia* powder has zinc concentration 2.20 ± 0.52%, after that for T1: 2.60 ± 0.58, T2: 3.10 ± 0.62, T3: 3.80 ± 0.66. Both whole wheat flour and *Fagonia indica* powder contribute to the zinc content of the developed nutraceutical crackers. Whole wheat provides a baseline level of zinc, while the incorporation of *Fagonia indica*, being a mineral-rich

medicinal plant, enhances the overall zinc concentration. Increased zinc intake through such fortified products supports immune function, growth, enzyme activity, and wound healing. Therefore, incorporation of *Fagonia indica* in nutraceutical crackers offers significant benefits in improving zinc intake and overall nutritional quality. Therefore, crackers can work as a functional food, supporting immunity and growth (Otho et al., 2022).

Table 4 *Effect of storage and treatment on Total Phenolic Content (TPC) ± S.D of Fagonia based nutraceutical crackers*

Treatments	0	15	30	Means
T_0	1.85 ± 0.5^{d}	1.68 ± 0.5^{d}	1.50 ± 0.7^{d}	1.68 ± 0.18^{d}
T_1	1.93 ± 0.5^{c}	2.04 ± 0.6^{c}	2.28 ± 0.7^{c}	2.08 ± 0.17^{c}
T_2	2.50 ± 0.6^{b}	2.80 ± 0.7^{b}	3.10 ± 0.8^{b}	2.80 ± 0.30^{b}
T_3	3.18 ± 0.6^{a}	3.20 ± 0.7^{a}	3.99 ± 0.8^{a}	3.46 ± 0.45^{a}
Overall Mean	2.37 ± 0.59^{c}	2.43 ± 0.58^{b}	2.72 ± 0.96^{a}	

The total phenolic content (TPC) of the formulated nutraceutical crackers was evaluated during storage at 0, 15, and 30 days. A noticeable variation in TPC values was observed among different treatments and storage intervals. In T0, the TPC value decreased from 1.85 ± 0.6 mg GAE/g on day 1 to 1.50 ± 0.7 mg GAE/g after 30 days of storage, indicating a slight reduction in phenolic compounds over time. This decline may be attributed to the degradation of heat- and oxidation-sensitive phenolic constituents during storage (Sharma et al., 2022).

Table 5 *Effect of storage and treatment on Radical Scavenging Activity (DPPH) % ± S.D of Fagonia based nutraceutical crackers*

Treatments	0	15	30	Means
T_0	33.2 ± 0.6^{d}	30.8 ± 0.5^{d}	28.4 ± 0.7^{d}	30.80 ± 2.40^{d}
T_1	36.7 ± 0.7^{c}	39.5 ± 0.6^{c}	36.2 ± 0.7^{c}	39.47 ± 3.25^{c}
T_2	39.9 ± 0.5^{b}	53.6 ± 0.7^{b}	49.8 ± 0.8^{b}	53.77 ± 4.05^{b}
T_3	59.8 ± 0.3^{a}	65.2 ± 0.7^{a}	60.7 ± 0.8^{a}	61.90 ± 2.89^{a}
Overall Mean	48.40 ± 0.52^{a}	47.28 ± 0.62^{b}	43.78 ± 0.75^{c}	

Radical scavenging activity of the nutraceutical cracker samples decreased gradually during storage from day 0 to day 30. The highest values were observed at day 0, followed by a decline at day 15 and day 30. This reduction is attributed to the degradation of phenolic and flavonoid compounds over time due to oxidation and environmental exposure. However, samples with higher levels of *Fagonia indica* retained greater antioxidant activity throughout the storage period, indicating improved stability of bioactive compounds in fortified formulations. T3 has the greater DPPH value that is 69.8 ± 1.1 % that is decreased to 60.7 ± 1.1 % after storage of 30 days. bThe treatment T_0 had only 33.2 ± 0.6 %of DPPH value because it does not have any amount of *Fagonia indica* powder which after 30 days of storage decline to 28.4 ± 0.7%. Values of T_1 and T_2 are also reduced after storage of 30 days period.

Table 6 *Effect of storage and treatment on Taste ± S.D of Fagonia based nutraceutical crackers*

Treatments	0	15	30	Means
T_0	7.5 ± 0.4^{c}	7.2 ± 0.6^{c}	6.9 ± 0.6^{c}	7.20 ± 0.30^{c}
T_1	7.7 ± 0.6^{b}	7.4 ± 0.7^{b}	7.1 ± 0.7^{b}	7.40 ± 0.30^{b}
T_2	8.0 ± 0.6^{a}	7.9 ± 0.6^{a}	7.4 ± 0.5^{a}	7.77 ± 0.32^{a}
T_3	7.2 ± 0.7^{d}	7.1 ± 0.4^{d}	6.8 ± 0.4^{d}	7.03 ± 0.21^{d}
Overall Mean	7.60 ± 0.34^{a}	7.40 ± 0.36^{b}	7.05 ± 0.27^{c}	

Taste remains one of the most important sensory attributes impacting consumer preference. As it reflects the combined perception of sweetness, bitterness, and flavor

balance. In this study, the scores of taste are impacted by both the incorporation of *Fagonia* powder and duration of storage. The scores of taste showed that from T_0 to T_2, flavor of the developed *Fagonia* based nutraceutical crackers is enhanced as these have moderate quantity of whole wheat flour which added sweetness and saltiness. Due to addition of more concentration of *Fagonia* powder in T_3, taste scores were declined as the product had the slightly bitter taste. Duration of storage also contributed to the decrease in taste scores as loss of freshness, lipid oxidation and moisture changes are some factors which cause the decrease in flavor enhancement and product's acceptability. According to a study by Öztürk et al. (2024), Taste-flavor scores showed a marked reduction in treatments where plant based substance "oleaster powder" was added at higher level, decreasing from 6.20 ± 0.70 to 4.60 ± 1.20, this decreasing trend suggested the development of undesirable bitter notes at elevated oleaster concentrations. Novotni et al. (2022) also reported values evaluated after tasting samples ranging from 1.7 to 4.7 in fiber-enriched crackers, indicating the presence of undesirable phytochemical compounds because the crackers had the increased amount of fiber in treatment 2 and 3.

Table 7 *Effect of storage and treatment on Texture ± S.D of Fagonia based nutraceutical crackers*

Treatments	0	15	30	Means
T_0	7.6 ± 0.5^{c}	7.3 ± 0.5^{c}	7.0 ± 0.4^{c}	7.30 ± 0.30^{c}
T_1	7.8 ± 0.6^{b}	7.5 ± 0.7^{b}	7.2 ± 0.5^{b}	7.50 ± 0.30^{b}
T_2	8.0 ± 0.7^{a}	7.7 ± 0.7^{a}	7.5 ± 0.6^{a}	7.73 ± 0.25^{a}
T_3	7.2 ± 0.5^{d}	7.0 ± 0.6^{d}	6.8 ± 0.7^{d}	7.00 ± 0.20^{d}
Overall Mean	7.65 ± 0.34^{a}	7.38 ± 0.30^{b}	7.13 ± 0.30^{c}	

Texture scores of the cracker samples improved with the incorporation of *Fagonia indica* up to an optimum level T_2, indicating enhanced crispness and structural quality due to the presence of dietary fiber. However, further increase in incorporation T_3 resulted in a decline in texture scores, possibly due to increased hardness caused by excessive fiber content. During storage, a gradual decrease in texture quality was observed from day 0 to day 30, which may be attributed to moisture absorption and loss of crispness. The standard deviation values remained within acceptable limits, indicating consistency in sensory evaluation. A study by Novotni et al. (2022) also reported increased hardness in high-fibre formulations up to 8.6, while Giannoutsos et al. (2023) found that high incorporation of plant based ingredient levels negatively affected texture and structural integrity. This decreasing trend showed that acceptability got lessened. Thus, these findings support my reasons.

Table 8 *Effect of storage and treatment on overall acceptability ± S.D of Fagonia based nutraceutical crackers*

Treatments	0	15	30	Means
T_0	7.5 ± 0.5^{c}	7.2 ± 0.6^{c}	6.9 ± 0.6^{c}	7.20 ± 0.30^{c}
T_1	7.7 ± 0.6^{b}	7.6 ± 0.7^{b}	7.1 ± 0.7^{b}	7.47 ± 0.32^{b}
T_2	8.1 ± 0.7^{a}	8.0 ± 0.8^{a}	7.3 ± 0.8^{a}	7.80 ± 0.44^{a}
T_3	7.2 ± 0.6^{d}	6.9 ± 0.7^{d}	6.5 ± 0.8^{d}	6.87 ± 0.35^{d}
Overall Mean	7.63 ± 0.33^{a}	7.43 ± 0.41^{b}	6.95 ± 0.31^{c}	

Overall acceptability scores of the cracker samples increased with the incorporation of *Fagonia indica* up to an optimum level (T_2), indicating improved sensory quality due to balanced enhancement of aroma, taste, and texture. However, further increase in incorporation (T_3) resulted in a slight decline in acceptability, possibly due to strong herbal flavor, increased bitterness, and textural hardness. During storage, a gradual decrease in overall acceptability was observed from day 0 to day 30, which may be attributed to loss of volatile compounds, flavor deterioration, and reduced crispness.

Conclusion

It can be concluded that *Fagonia indica* is a highly valuable medicinal plant with strong potential for use in functional food development. Its rich phytochemical composition, particularly flavonoids and polyphenolic compounds, contributes significantly to its antioxidant, anti-inflammatory, and hepatoprotective properties. The incorporation of *Fagonia indica* into nutraceutical crackers successfully enhanced their nutritional and functional quality. The study demonstrated that the plant-based formulation improved dietary fiber, antioxidant capacity, and mineral content while maintaining acceptable sensory characteristics. This highlights the feasibility of developing health-oriented bakery products using indigenous medicinal plants. From a hepatoprotective perspective, *Fagonia indica* offers promising benefits due to its ability to reduce oxidative stress, inhibit lipid peroxidation, and support cellular antioxidant defense systems. These mechanisms are directly associated with liver protection and the prevention of liver damage. Regular dietary intake of such functional products may contribute to improved liver health and overall metabolic balance. Furthermore, the study supports the growing concept of functional foods as preventive nutritional tools against lifestyle-related disorders. The utilization of *Fagonia indica* in cracker formulation not only adds value to traditional bakery products but also promotes the use of underutilized medicinal plants in modern food systems. In conclusion, *Fagonia indica*-based nutraceutical crackers represent a novel, effective, and acceptable functional food product with potential health-promoting and hepatoprotective benefits. Future research may focus on clinical validation, long-term stability, and large-scale production feasibility to further establish its role in functional nutrition and disease prevention.

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