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Original article

Blockchain technology for enhancing sustainable food systems: A consumer perspective

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Summary This paper explores the potential of blockchain technology (BCT) in promoting sustainable food production and consumption (SFPC) from a consumer perspective. India, a significant global food producer, faces challenges related to affordability and food logistics due to transport and labour constraints. Food safety concerns, that is, foodborne illnesses and quality issues, alongside unexpected events like COVID-19 and geopolitical conflicts, threaten SFPC. In recent times, consumer focus has shifted a lot towards food safety and security. The study adopted exploratory factor analysis (EFA) to identify the factors strengthening consumer trust through BCT. The EFA helped classify the items into five factors, that is, reliability, sustainability, impact on health, trust and switching intentions. The results reveal that these factors are the most significant reasons consumers are willing to accept a blockchain-enabled food system over a traditional system. The study findings will benefit organisations willing to introduce blockchain within their operations to improve the consumer base. It will also prove to be helpful for researchers and academicians to understand consumer perspectives towards BCT for SFPC.

Keywords Blockchain technology, consumer acceptability, exploratory factor analysis, food production and consumption, food supply chains, food traceability, sustainability.

Introduction

A food supply chain (FSC) is '*a network of interconnected firms that collaborate closely to manage the flow of goods and services along the value-added chain. Food and agriculture products to achieve exceptional consumer value at little expense*' (Duan *et al*., 2020). Sustainable food supply chain (SFSC) is a consumer-driven, holistic term that refers to the coordinated adoption of environmentally friendly food consumption and production patterns that respect the carrying capacity of natural ecosystems (Nayak & Dhaigude, 2019). The FSC covers food processing from producers/farmers to consumers (Mangla *et al*., 2021). FAO-defined SFSC ensures food security and nutrition without compromising the environmental, social and economic underpinnings needed to ensure safe food for future generations. Sustainability requires social fairness, environmental conservation and economic prosperity (Hajirasouli & Kumarasuriyar, 2016). Economic sustainability involves processing that fulfils current consumption through resilience and productivity without compromising future needs (Agnusdei & Coluccia, 2022). It boosts the firm profitability through high-quality products with reduced waste, enhanced customer satisfaction and improved long-term performance (Bishop, 2021).

The study systematically reviewed the literature (Yadav & Desai, 2016). The research protocol adopted included keywords used to extract the literature were 'sustainability', 'blockchain technology', 'food production and consumption', 'consumer acceptability' and inclusion of articles focused on the food industry, blockchain technology and consumer acceptability. The concept of sustainability in the supply chain emerged in the early 2000s, according to Silvestre (2015). Therefore, the time horizon for the present study spans from 2000 to 2022. Search databases utilised for the study were 'Scopus' to ensure quality.

Global emergencies, such as COVID-19, have starkly exposed vulnerabilities in FSCs, driven by government lockdowns and constraints, closed or partially operating businesses and limited locations disrupted production schedules and reduced workforce during

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quarantines. Additionally, geopolitical conflicts like Russia-Ukraine war have sent shockwaves through the food sector by inflating prices of essential commodities like Indian wheat and edible oil (Nazeeruddin & Pradesh, 2022), with the ripple effect extending to food prices, since Russia is the third largest producer of crude oil, so rising fuel prices instantly affect food prices, especially perishables due to logistics expenses. Food and gasoline make up one-third of wholesale and 39.1% of retail inflation (Jagtap *et al.*, 2022).

Blockchain technology (BCT) emerges as a transformative force (Kouhizadeh *et al.*, 2021; Hollands *et al.*, 2018). Satoshi Nakamoto's BCT with a decentralised, transparent and secure network empowers peer-to-peer transactions, offering supply chain efficiency, traceability and the ability to address issues like food recalls. Furthermore, it aligns with SDG 12 (Responsible Consumption and Production) by reducing waste and pollution throughout the FSC (Mirabelli & Solina, 2020).

This study examines BCT's role in SFPC from a consumer perspective. Previous studies have examined the pros and drawbacks of using blockchain in operations and its role in sustainable development, but they have not examined consumer perceptions of BCT (Singh *et al.*, 2021) (Table 1). BCT factors can empower consumers to make better decisions and build trust in the food production and supply chain, enabling increased consumer engagement with the sustainable food system (Crew, 2019; Castellini *et al.*, 2022). The study used factor analysis to uncover BCT characteristics that boost FSC consumer trust.

Methods

The study identified the factors affecting consumer acceptability of BCT for SFPC using a factor analysis approach. EFA is frequently used when there are no postulates concerning the nature of the factor structure and when determining internal consistency (Kharub *et al.*, 2022). The study identified forty criteria for investigation through a literature review. EFA was performed with IBM SPSS statistical software, the principal component analysis method and varimax rotation and the results were within the acceptable range. Based on a literature study, a systematic questionnaire was developed to determine the factors affecting consumer perspective of BCT in SFPC. The questionnaire contained forty items related to affecting consumers' acceptance towards BCT in FSC. These items were rated on a five-point scale ranging from 1 (strongly disagree) to 5 (strongly agree).

The study used a non-probabilistic convenience sampling technique based on the researcher's judgement (Curvelo *et al.*, 2019). This study employed a quantitative research methodology which involved data collection through online surveys and personal visits. An online survey is a method for collecting data over the Internet, which has advantages like cost-effectiveness, shorter timer requirements for implementation and ease of analysis but comes with challenges like non-response bias and privacy concerns (Wu *et al.*, 2022). A personal visit is a one-on-one conversation between a researcher and a participant, typically in person, it allows for nuanced insights but can be resource-intensive (Rahman, 2023). Sakaluk & Short (2016) suggested a sample size between 200 and 250 is suitable for conducting EFA. Beavers *et al.* (2013) emphasise that factor analysis sample size depends on factor and their item loadings. If the factors include four or more items with loadings of 0.60 or more, the sample size is not relevant. A sample size of 150 or more is required to be confident in the results if factors comprise 10–12 items that load substantially 0.40 or more. Therefore, a total of 265 responses were collected, out of which fifty-four were excluded due to lack of clear pattern, incomplete responses and few were excluded being multivariate outliers. The study aimed to get the consumers' perspectives *via* online surveys and personal visits; the ratio was ~10:1. It was ensured that respondents were aware of the concept of traceability and its applications in food products to attain reliable responses. Finally, a sample of 211 respondents from India was considered for the study. Table A1 represents the demographic profile of respondents.

Analysis and results

Exploratory factor analysis was conducted in a structured manner. The forty issues referred to as items were evaluated for EFA. First, the study conducted a multivariate analysis to comprehend how the outcome variables relate or what fundamental factors produce the observed outcomes in the dependent variables; we eliminated 16 responses for being multivariate outliers (Zeynivandnezhad *et al.*, 2019). Next, data reliability was tested using the Cronbach alpha coefficient, which examines homogeneity, equivalence and intercorrelation between items. The Cronbach alpha value for this analysis, performed using IBM SPSS software, was 0.9. The calculated Cronbach alpha value indicates high reliability between components and items. The Bartlett test of sphericity was utilised to validate the applicability of factor analysis, which was evaluated by looking at the data's correlation matrix (Hair *et al.*, 2010). Simultaneously, sample adequacy was determined using Kaiser-Meyer-Olkin (KMO) statistics (Table 2). EFA was performed using principal component analysis (PCA) with Kaiser normalisation (eigenvalue > 1) and varimax rotation in SPSS. The extraction of this led to five components.

The KMO score of greater than 0.6 reflects as significant and determines the applicability of factor analysis; it was 0.964 for the consumer acceptability factors.

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Table 1 Consumers' perception to blockchain in food products

Item Code	Items	Source
T1	Provides sufficient objective information about processed food products.	(Nguyen *et al.*, 2021)
T2	Provides true information	Apostolidou *et al.* (2018)
T3	Provides reliable information	
T4	Provides transparent information	
T5	Provides accurate information	
T6	Label is a signal of the product's safety assurance	
T7	Improves my trust in manufacturers and retailers	
H1	Will help in maintaining my health	Nguyen *et al.* (2021)
H2	Will help in maintaining my family's and friends' health	Qian *et al.* (2020)
H3	Will ensure more health benefits as compared to normal products	
S1	Will ensure the sustainability of food products	Nguyen *et al.* (2021)
S2	Will be beneficial for the environment	Qian *et al.* (2020)
S3	Will ensure efficient utilisation of resources	
S4	Will be beneficial for the economy	
O1	Will provide security by providing information about product's origin	Rodriguez-Salvador & Dopico (2020)
O2	Makes me feel more assured by giving information about product's origin	
O3	Will positively impact my purchase intentions as complete information about the origin is provided.	
O4	Will enhance my loyalty by providing information about the origin	
PU1	Reduces the degree of uncertainty associated with processed food products	Nguyen *et al.* (2021)
PU2	Reduces the degree of uncertainty associated with the post-purchase reaction of processed food products	
PU3	Help me identify the major risks and uncertainties	
PU4	Builds up my confidence by providing prior knowledge regarding the risk areas	
Q1	Improves the quality and nutritional value of processed food products	Apostolidou *et al.* (2018)
Q2	Assures better quality of processed food products	
Q3	Makes manufacturers more stringent towards quality	
Q4	Is the proof that the product has undergone a quality control?	
Q5	Is the medium for me to be assured of higher quality products?	
FS1	Assures me that product is safe and risk-free	Apostolidou *et al.* (2018)
FS2	Enables quick identification of poor-quality food products	Rodriguez-Salvador & Dopico (2020)
FS3	Assures me that my product is fit for consumption	
FS4	Assures me of legal and certified ingredients	
I1	Is the medium for me to verify the information on the label?	Rodriguez-Salvador & Dopico (2020)
I2	Is the medium for me to get trusted information regarding my product?	
I3	Is the medium for me to know the product processing method?	
I4	Is the medium for me to know all the ingredients of the product?	
I5	Is the medium to get information regarding the preservatives used for my product?	
I6	Will ensure that the retailer gives me the correct information	
SI1	Is the reason I am strongly considering switching from non-traceable to traceable food products?	Nguyen *et al.* (2021)
SI2	Assures me that my decision to switch is correct	
SI3	Gives me the confidence to switch to better food products	

Table 2 KMO and Barlett test

Kaiser-Meyer-Olkin measure of sampling adequacy	0.964
Bartlett's test of sphericity	
Approx. Chi-Square	7678.483
Df	780
Sig.	0.000

Bartlett's sphericity test was highly significant, indicating the link between the population's attributes. The commonality value for every trait was at least 0.603. EFA experiment grouped forty items into five main components, that is, reliability, sustainability, impact on health, trust and switching intentions. The commonalities give the percentage of variance among the 40 items as determined by the five components. Table 3 shows that all the elements have a commonality of at least 0.5 (Hair *et al.*, 2010). Every item has factor loading ≥0.55; hence, these are considered valid.

Discussions

This study identifies consumers' viewpoint on BCT for SFPC. This study aids academics, professionals and decision-makers in understanding the factors affecting

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Table 3 Exploratory factor analysis

Factors	Items	Eigen value	Communalities	Factor loadings				Measurement on a likert scale			Total variance
				F1	F2	F3	F4	F5	Mean	SD	
Reliability											
F1	Is the medium for me to be assured of higher quality products	1	0.770	0.798					4.88	0.993	21.747
	Makes manufacturers more stringent towards quality	1	0.702	0.748					5.02	0.891	
	Assures me that the product is safe and risk-free	1	0.718	0.739					4.87	0.955	
	Assures better quality of processed food products	1	0.730	0.730					4.94	0.931	
	Help me identify the major risks and uncertainties	1	0.687	0.71					4.88	0.946	
	Assures me that my product is fit for consumption	1	0.717	0.70					4.85	0.944	
	Reduces the degree of uncertainty associated with the post-purchase reaction of processed food products	1	0.690	0.708					4.80	0.946	
	Builds up my confidence by providing prior knowledge regarding the risk areas	1	0.697	0.694					4.90	0.896	
	Is the proof that the product has undergone a quality control	1	0.647	0.694					4.90	0.956	
	Is the medium for me to verify the information that appears on the label	1	0.782	0.691					4.96	0.906	
	Is the medium for me know the product processing method	1	0.752	0.666					4.83	0.918	
	Enables quick identification of poor-quality food products	1	0.626	0.665					4.88	0.976	
	Reduces the degree of uncertainty associated with processed food products	1	0.633	0.664					4.90	0.889	
	Assures me of legal and certified ingredients	1	0.710	0.663					5.00	0.915	
	Is the medium for me to get trusted information regarding my product	1	0.753	0.645					4.98	0.855	
	Will enhance my loyalty by providing information about the origin	1	0.674	0.630					4.93	0.902	
	Improves the quality and nutritional value of processed food products	1	0.724	0.624					4.80	0.999	
	Will positively impact my purchase intentions as complete information about the origin is provided	1	0.693	0.618					5.06	0.888	
	Is the medium for me to know all the ingredients of the product	1	0.724	0.597					5.00	0.893	
	Is the medium to get information regarding the preservatives used for my product	1	0.693	0.588					4.97	0.925	
Sustainability											
F2	Will be beneficial for the environment	1	0.752		0.666				4.74	1.012	1.649
	Will assure the sustainability of food products	1	0.750		0.660				4.87	0.935	
	Will assure efficient utilisation of resources	1	0.696		0.652				4.78	0.991	
	Will be beneficial for the economy	1	0.644		0.632				4.78	0.982	
	Will provide security by providing information about the product's origin	1	0.767		0.591				5.05	0.984	
	Makes me feel more assured by giving information about product's origin	1	0.761		0.615				5.06	0.941	
Impact on Health											
F3	Will help in maintaining my health	1	0.771			0.691			4.88	0.992	1.036
		1	0.719			0.645			4.85	0.964	

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Table 3 (*Continued*)

Factors	Items	Eigen value	Communalities	Factor loadings				Measurement on a likert scale			Total variance
				F1	F2	F3	F4	F5	Mean	SD	
	Will help in maintaining the health of my family and friends										
	Will ensure more health benefits as compared to normal products	1	0.657			0.610			4.86	1.009	
Trust											
F4	Provides sufficient objective information about processed food products	1	0.567				0.595		4.97	0.906	2.555
	Provides true information	1	0.741				0.787		4.78	0.971	
	Provides reliable information	1	0.716				0.758		4.81	0.915	
	Provides transparent information	1	0.709				0.778		4.83	0.865	
	Provides accurate information	1	0.764				0.797		4.65	0.991	
Switching intentions											
F5	Is the reason I am strongly considering switching from non-traceable to traceable food products?	1	0.754					0.679	4.98	0.901	1.225
	Assures me that my decision to switch is correct	1	0.767					0.580	4.95	0.882	
	Gives me the confidence to switch to better food products	1	0.776					0.603	5.03	0.947	
	Will ensure that the retailer gives me the correct information (*e.g.* expiry date of ingredients, origin, chemicals/allergens used)	1	0.704					0.589	4.95	0.914	

Notes: Extraction method: principal component analysis; Rotation method: varimax with Kaiser normalisation; F1–F5 represents individual components.

consumer acceptability of the role of BCT in sustainable food systems. Our findings will help scholars grasp BCT's significance in SFPC from a consumer perspective. BCT implementation/applications, benefits and challenges in food chains dominate most literature, while consumer opinions are lacking. Very few research has proposed consumer acceptance of BCT in food supply networks, thus, exploring characteristics that promote consumer acceptance of BCT is crucial (Rejeb *et al.*, 2022). The empirical analysis revealed five components that are the most significant reasons for consumers to accept a blockchain-enabled food system over a traditional system.

The first factor identified is reliability (F1), the study reveals that customers are willing to accept BCT for SFPC for food to be more reliable, from raw material origin to processing stages, preservatives, *etc*. This will also eliminate processed food product uncertainty and reassure consumers. Consumers value a BCT-based traceability system, indicating that traceability improves quality perceptions and buying decisions. According to Ran *et al.* (2022), BCT ensures complete traceability, resulting in enhanced quality and safety of food products. This shows how well BCT may facilitate supply chain traceability and integrity (Sander *et al.*, 2018).

Sustainability is the second factor (F2) identified. Blockchain helps in SFPC, which ensures proper utilisation of resources which benefit the economy and human health. This is one of the major factors affecting consumers' acceptability. The study findings align with Ran *et al.* (2022) and Castellini *et al.* (2022). Consumer demand for sustainable food products may be addressed by implementing BCT-enabled systems in supply chains. Consumers are aware that their food consumption decisions impact the environment.

The third factor, health (F3), shows that consumers think blockchain-enabled food systems would be healthier than traditional ones since the chain will be more open. Fraud will decrease as producers and retailers are more diligent throughout the food system. Zhai *et al.* (2022) found that educated buyers are clearer about health risks and more motivated to buy blockchain-traceable products. Education and information may help consumers perceive health concerns and embrace healthy food.

According to the results, trust (F4) has also been identified as one of the significant factors Blockchain-

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enabled food systems provide objective, transparent and reliable information to build consumer trust. Alazab *et al.* (2021) found that technological trust increases blockchain adoption. According to the study, confidence in technology favourably affects people's decision to shun or welcome technology. Trust is a significant indicator of the user's intention. The fifth factor, switching intentions (F5), reveals that if quality assurance, correct information and complete details regarding the food product are provided, consumers are willing to switch to brands implementing blockchain-enabled food systems rather than traditional food systems even at a higher price. The findings align with Dionysis *et al.* (2022), who examined the factors influencing consumer purchase intentions for BCT-enabled food systems. As per the study, blockchain-traceable food products will have higher production standards, be environmentally friendly and be safe. It also concluded that consumers believe food products will taste better and be greener.

The study findings can also help develop managerial theories which can help improve businesses' productivity. BCT could solve existing food chain traceability and transparency issues like exact information transfer, consumer-friendly traceability and cost savings by eliminating intermediaries. BCT-enabled systems provide correct food information. Consumers will benefit from BCT in FSC since they will have more information on sustainable food production. This study shows that a fully BCT-enabled system affects consumers' quality perceptions and purchase decisions, thus organisations should rethink their business and information exchange methods. Since most firms would find such a large transformation too disruptive, it requires highly trained management and manpower with a mindset to bring change. BCT should be introduced to the food industry gradually. The study findings identify that customers rely on their judgements of quality and choices of food products on a comprehensive traceability system which can be obtained with the help of BCT; food industry professionals and managers should consider BCT adoption. Businesses should adopt an idealistic mindset and pay attention to the expressed preferences of stakeholders to achieve this (Panghal *et al.*, 2022).

Conclusion

The present study aims to meet the research gaps by examining the potential of BCT to enable greater consumer engagement with sustainable food systems. The key factors affecting consumer acceptability were explored through a pre-structured questionnaire, and forty items were considered for factor analysis. EFA was performed using SPSS with a PCA technique and varimax rotation, and it was determined to be applicable when all values fell inside the tolerance level. The result of the data analysis diminished the 40 items into five components, that is, reliability, sustainability, impact on health, trust and switching Intentions, respectively. BCT may not immediately benefit the company but will enhance consumer involvement and provide a sustained competitive advantage. Blockchain can help businesses address a variety of issues related to consumer engagement. Understanding and implementing advanced technology, such as blockchain, in any organisation will prepare it for the future and facilitate the achievement of organisational objectives. The findings suggest that consumers can feel dissatisfied with traditional food systems for issues like late delivery without warning, low-quality items, damaged goods owing to defective handling and expensive or inaccurate goods. No decisive outcomes are ever gained despite putting in substantial money and effort, and these challenges can be easily handled by blockchain technology, thus improving the sustainability and overall quality of the system.

Despite the valuable findings, the study has a few limitations. Due to differences in location, age and income, the respondents were not directly comparable. Also, the respondent's experience in the agri-food business differed. Future research may move beyond the current exploratory phase and conduct scientifically rigorous, higher-quality studies more firmly found in data analysis and methodology. Also, future studies may extend the findings to conduct comparative studies across different regions and may explore the influence of demographic variables on consumer perception towards BCT.

Conflict of Interest Statement

The authors declare no conflict of interest.

Author contributions

Anupama Panghal: Conceptualization (equal); data curation (equal); formal analysis (equal); investigation (equal); methodology (equal); project administration (equal); supervision (equal); validation (equal); visualization (equal); writing – original draft (equal); writing – review and editing (equal). **Sharmistha Pan:** Data curation (equal); formal analysis (equal); investigation (equal); methodology (equal); validation (equal); writing – original draft (equal); writing – review and editing (equal). **Priyanka Vern:** Conceptualization (equal); data curation (equal); formal analysis (equal); investigation (equal); methodology (equal); supervision (equal); validation (equal); visualization (equal); writing – original draft (equal); writing – review and editing (equal). **Rahul S. Mor:** Formal analysis (equal); investigation (equal); methodology (equal); project

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administration (equal); supervision (equal); validation (equal); writing – original draft (equal); writing – review and editing (equal). **Sandeep Jagtap:** Investigation (equal); methodology (equal); supervision (equal); validation (equal); writing – original draft (equal); writing – review and editing (equal).

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Appendix

Table A1 Demographic profile (n = 211)

Sr. No.	Respondent's demographic profile	%
1.	Gender	
	Male	54%
	Female	64%
2.	Age	
	18–30	80%
	30–45	15%
	45+	5%
3.	Highest educational level	
	High school	17%
	Graduate	42%
	Post-graduate	31%
	Doctorate, and post-doctorate	10%
4.	Household annual income (lakhs)	
	<2 lakhs	29%
	2–6 lakhs	32%
	6–10	24%
	>10 lakhs	15%

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