



*Research article*

## **HACCP compliance in organic food processing industries in India: A statistical study by product type and company size.**

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**Abstract:** Organic food is gaining global popularity due to its perceived health benefits and compatibility with sustainability goals. However, the application of hazard analysis and critical control point (HACCP) in organic food processing, particularly in developing countries, is barely discussed. In this study, we examined the level of HACCP compliance in certified organic food processing units in Kerala, India, with an emphasis on the impact of product type and company size. In 2023-2024, a structured audit based on Codex criteria was carried out, with a standardized scoring system used to evaluate the paperwork and operational performance. Significant trends and interactions were identified using statistical methods, including two-way ANOVA, Tukey's HSD post hoc test, principal component analysis (PCA), and cluster analysis. Across product categories, there were notable variations in HACCP compliance, with meat and ready-to-eat food processors showing higher levels of compliance than dairy and rice-based processors. Company size was also an important determinant, with larger enterprises demonstrating superior system implementation. Significant interaction effects demonstrated that performance patterns were not consistent across categories. Significant interaction effects between product type and company size indicated that compliance patterns vary depending on the combination of these factors. These findings underline the importance of targeted training, regulatory support, and the incorporation of HACCP into organic certification frameworks to enhance food safety standards in the organic industry, particularly among small-scale and high-risk processors in developing countries.

**Keywords:** HACCP; food safety; organic food; audit; HACCP compliance; organic food processing

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## 1. Introduction

The increasing demand for safe, high-quality, and sustainably produced food contribute to the popularity of the organic food industry worldwide, including India [1]. Consumers connect organic products with minimum chemical use and natural processing, so ensuring food safety compliance in this industry is critical, not only to satisfy regulatory standards but also to maintain customer trust [1,2].

The Hazard Analysis and Critical Control Points (HACCP) method has emerged as a globally recognized framework for ensuring food safety by identifying and addressing possible hazards throughout the food production process [3]. While HACCP has been extensively studied and implemented in conventional food industries, its application in the organic food processing sector is mostly unexplored, particularly in developing economies such as India, where organic certification systems are maturing and enterprise diversity is widespread. The Food Safety and Standards Authority of India (FSSAI) advises and mandates Food Safety Management Systems (FSMS) based on HACCP for food businesses in specified product categories. HACCP is mandatory for enterprises that export food, particularly in sectors like seafood and meat [4,5]. India is one of the biggest producers of organic food in terms of volume and area [6]. The organic food industry in India is governed by two major regulatory regimes, with varying roles depending on whether the product is for domestic sale or export: The Participatory Guarantee System (PGS-India) and National Programme for Organic Production (NPOP). HACCP is not mandatory under NPOP or PGS, but it is increasingly adopted by export-focused or high-risk product companies [5–7]. The Ministry of Commerce and Industry of the Government of India manages the Agricultural and Processed Food Products Export Development Authority (APEDA), a statutory body tasked with promoting, certifying, and facilitating the export of agricultural and processed food products, including organic products [6].

The literature on HACCP has focused on conventional food processing industries or general food safety challenges [8–12]. However, organic food processing presents distinct structural and operational challenges. In contrast to the highly regulated conventional food industry, many organic food processing businesses in India are small or medium-sized, with little administrative and technical infrastructure. The degree and uniformity of HACCP system implementation among organic processors vary significantly as a result of this structural variance [13–17]. Small-scale producers often lack the technical capacity to implement systems like HACCP. To date, there is a notable lack of published literature addressing the HACCP systems within the organic food processing sector [18–20]. Effective implementation of food safety management systems like HACCP is difficult in many developing nations, despite the promotion of organic food production as a sustainable alternative to conventional agriculture [1]. Organic processors' ability to develop, implement, and maintain reliable HACCP systems is directly impacted by limitations on expertise, structured training, and regulatory guidelines, especially in small businesses [21,22].

Thus, through a systematic audit-based assessment and multiple statistical analyses, we intend to measure HACCP compliance among certified organic food processors in Kerala, India, and investigate how compliance levels vary according to company size and product type. This can help regulatory agencies and certification bodies develop targeted interventions that address the needs of underperforming groups [15,23]. Moreover, this provides insight into how food safety capacity is distributed across types of processors, which is vital for building resilient and equitable food supply chains. Finally, such analysis supports the development of more tailored training, policy, and resource allocation strategies to strengthen food safety in the organic sector.

We respond to these gaps by focusing on HACCP compliance among organic food processors in Kerala, India. Additionally, we seek to examine the relationship between company characteristics, particularly company size and product category, and their food safety performance, as measured through structured HACCP audits.

## 2. Materials and methods

### 2.1. Study design and data collection

This study is an audit-based investigation conducted to evaluate the level of HACCP compliance in organic food processing industries in Kerala, India. Our aim was to assess the impact of company size and product type on HACCP functioning and adherence within these facilities. The study was carried out from 2023 to 2024. A total of 100 organic food processing companies were selected to ensure representation across product categories and company sizes. The convenience-based sampling method was used. The selection process was executed with the help and collaboration of a private organic food certification agency in India. To enable comparative investigation of HACCP compliance patterns, classification by product category and company size was used. To guarantee uniformity and comparability of audited units, eligibility criteria were established before sampling. Businesses that met the following criteria were included: (1) They were certified organic food processing firms operating under recognized certification schemes (NPOP or PGS-India); (2) they were based in Kerala; and (3) they consented to take part in a HACCP compliance audit.

Enterprises were excluded if they: (1) Lacked appropriate organic certification at the time of assessment; (2) were not operational during the audit window; or (3) denied or were unable to provide access to documents, facilities, or relevant individuals required for the audit. The final sample of 100 audited corporations comprised only businesses that satisfied all inclusion criteria and none of the exclusion criteria.

Kerala was selected as the research region because it is one of the leading Indian states in the development and promotion of organic agriculture and organic food processing. The state has a comparatively large number of certified organic food processing businesses working under NPOP and PGS-India systems, and it has adopted several government-sponsored organic cultivation and certification initiatives. This offered a sizable and varied sampling frame that covered a wide range of product categories and business sizes.

**Table 1.** Structured audit questionnaire based on Codex HACCP principles [24].

Questions	2	3	4	5
PART I				
Block 1 Step 1. Assemble the HACCP team				
1. Was the HACCP team assembled in the enterprise?				
2. Was it a multidisciplinary team?				
3. Were all team members trained in HACCP?				
4. Was the HACCP plan developed?				
5. Did the team consist of people with an understanding of particular biological, chemical, and physical hazards and associated risks?				

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Questions	2	3	4	5
6. Did the team consist of people involved in the production process?				
7. Did the team consist of people with knowledge in microbiology, hygiene, and food technology?				
Block 2 Step 2. Describe product				
1. Were products described?				
2. Where all range of products described?				
3. Was the description of the products made properly?				
4. Was the composition of products described, including all raw materials, ingredients, and additives?				
5. Was the composition of products complete?				
6. Was the type of product processing specified?				
7. Was it specified how the product should be packaged?				
8. Were the microbiological parameters of the product specified?				
9. Were the chemical parameters of the product specified?				
10. Were the sensory parameters of the product specified?				
11. Were the physical parameters of the product specified?				
12. Was it specified how the product should be stored?				
13. Was it specified how the product should be transported and distributed?				
14. Was the durability term of the product specified?				
15. Is the labeling information appropriate?				
Block 3 Step 3. Identify intended use				
1. Was the intended use of all products specified?				
2. Was the nature of the target group for the product specified?				
3. Did the target group include infants?				
4. Was the target group elderly people?				
5. Was the target group adults?				
6. Was the target group included, allergic or malnourished people?				
7. Was the intended use of products defined?				
Block 4 Step 4. Construct a flow diagram				
1. Were detailed flow diagrams drawn up?				
2. Did the flow diagrams include all raw materials, ingredients, and additives?				
3. Did the flow diagrams include packaging?				
4. Was the sequence of all production steps established?				
5. Did the flow diagrams include technical parameters of raw materials?				
6. Did the flow diagrams include technical parameters of byproducts?				
7. Did the flow diagrams include technical parameters of final products?				
8. Did the flow diagrams include breaks between production steps?				
9. Did flow diagrams exclude the risk of cross-contamination?				
10. Were procedures for cleaning and disinfection established?				
11. Was the hygienic environment of the production process provided?				
12. Did employees maintain hygiene during the production process?				
13. Were adequate conditions of storage and distribution of products ensured?				

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Questions	2	3	4	5
<b>Block 5 Step 5. On-site confirmation of flow diagram</b>				
1. Was on site conformation of the flow diagram made?				
2. Was flow diagram confirmation made during the production process?				
3. Was there evidence of performed confirmation?				
4. Was on site conformation made by the HACCP team?				
<b>Block 6 Step 6. Principle I. Identify and analyze hazards</b>				
1. Was a list of possible hazards made?				
2. Was a list made for all steps in accordance with the developed product flow diagrams?				
3. Did the list include physical hazards?				
4. Did the list include chemical hazards?				
5. Did the list include microbiological hazards?				
6. Did the list include biological hazards?				
7. Were causes of possible hazards specified?				
8. Were preventive actions that eliminate or reduce hazards established?				
9. Were the undesirable health influences of the mentioned hazards specified?				
10. Were survival and multiplication of pathogenic microorganisms considered?				
11. Were the formation of chemicals in products and the production environment considered?				
12. Were allergens in products considered?				
13. Was the possibility of secondary pollution between raw materials, intermediate, and finished products considered?				
14. Were control measures for specific hazards specified?				
15. Were all control measures assigned to existing procedures and specifications?				
<b>Block 7 Step 7. Principle II. Determine Critical Control Points (CCPs)</b>				
1. Were CCPs established?				
2. Were methods leading to the determination of CCPs specified?				
3. Was a decision tree used to determine CCPs?				
4. Was a decision tree used in accordance with flow diagrams at each production step?				
5. Was a decision tree applied for each hazard at each production step?				
6. Did the HACCP team members receive training on the use of the decision tree, and was it evidenced?				
7. Were CCPs identified properly?				
8. Whether any step, for which CCP should be determined, was omitted?				
<b>Block 8 Step 8. Principle III. Establish critical limits for each CCP</b>				
1. Were parameters and critical limits established for each CCP?				
2. Were parameters and critical limits acknowledged in the documentation?				
3. Do critical limits correspond to the acceptable border values about product safety?				
4. Were critical limits set for observable or measurable parameters that could show that CCP is under control?				
5. Were limits based on reasonable assumptions?				
6. Were critical limits properly chosen in each CCP?				

*Continued on the next page*

Questions	2	3	4	5
<b>Block 9 Step 9. Principle IV. Monitoring of CCPs</b>				
1. Were monitoring systems for all CCPs established?				
2. Were monitoring procedures for each CCP elaborated?				
3. Was the frequency of monitoring established?				
4. Was the frequency of monitoring established properly?				
5. Were there monitoring methods established?				
6. Were monitoring methods adequate?				
7. Were employees responsible for monitoring the designated?				
8. Were there CCPs monitoring devices used?				
9. Were monitoring devices showing reliable measurements?				
10. Were there available control cards to record the results of monitoring for each CCP?				
11. Did control cards allowed keeping of records of all monitored parameters in CCPs?				
<b>Block 10 Step 10. Principle IV. Establishing corrective action</b>				
1. Were there corrective actions for each CCP established, in the case when monitoring results indicated a loss of control?				
2. Were corrective actions fully ensured a return to the assumed parameters?				
3. Were there corrective actions procedures for each CCP established?				
4. Were there designated employees responsible for corrective actions for each CCP?				
5. Were there control cards to document the corrective action taken at all established CCPs?				
6. Was there instruction of specified use of products obtained during the period when CCP was out of control?				
<b>Block 11 Step 11. Principle VI. Verification procedures</b>				
1. Were methods of HACCP verification established?				
2. Was the frequency of HACCP verification established?				
3. Were established verification methods appropriate?				
4. Was established frequency of HACCP verification adequate?				
5. Were verification procedures established to confirm that the HACCP system was effective and consistent with the plan?				
6. Was an employee responsible for analyze of verification results designated?				
7. Did verification included the accuracy of records?				
8. Did verification included also asking questions of employees, especially ,CCP monitors?				
9. Did verification included observation of operations at CCPs?				
10. Did verification included calibration of monitoring devices?				
<b>Block 12 Step 12. Principle VII. Recordkeeping and documentation</b>				
1. Was there any documentation of the HACCP system available?				
2. Was there any documentation available documentation on the implementation steps of the HACCP system?				
3. Was there way of documenting supervision established?				
4. Was the way of archiving system documentation established?				
5. Was a time archiving documents specified?				

*Continued on the next page*

Questions	2	3	4	5
6. Was there a way to make amendments in the control cards specified if the employee made a mistake?				
7. Were all documents properly marked, and was it possible their unambiguous identification?				
8. Was a method of exchanging outdated document to the current version established?				
PART II				
Block 1 Step 7. Principle II. Determine Critical Control Points (CCPs)				
1. Did employees working in the CCP area knew that in this step CCP was established?				
2. Did employees working in the CCP area knew what the CCP established for?				
3. Could supervisor of HACCP system listed all CCPs?				
4. Could manager of evaluated enterprise listed all CCPs?				
Block 2 Step 8. Principle III. Establish critical limits for each CCP				
1. Did employees working in the CCP area knew parameters of critical limits at this CCP?				
2. Did employees working in the CCP area knew values of critical limits parameters at this CCP?				
3. Did employees responsible for monitoring of CCPs know the Parameters and critical limits at CCPs for which they are responsible?				
4. Did supervisor of HACCP system knew parameters and critical limits for all established CCPs?				
Block 3 Step 9. Principle IV. Monitoring of CCPs				
1. Did the CCP monitoring procedures were available to employees responsible for each CCP?				
2. Did employees knew the monitoring procedure at the CCP for which they are responsible?				
3. Whether employees responsible for monitoring at the CCP were aware of their responsibility for food safety?				
4. Were results of CCPs monitoring recorded regularly?				
5. Were entries in CCPs control cards completed?				
6. Were results of CCPs monitoring regularly evaluated by supervisor or competent person?				
7. Were control cards located at easily accessible place which allowed records keeping?				
Block 4 Step 10. Principle V. Establish corrective action				
1. Did employees working in the CCP area knew procedures of corrective action at the CCP for which they are responsible?				
2. Could employees responsible for the CCP explain the way of action in case of exceeding the critical limit at the CCP?				
3. Whether employees responsible for corrective actions at the CCP for which they are responsible were aware of their responsibility for food safety?				
4. Were corrective actions always took when control was lost in all the CCP?				
5. Were control cards located at easily accessible place which allowed records keeping?				
6. Were records of actions taken in line with the procedures of corrective actions?				

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Questions	2	3	4	5
<b>Block 5 Step 11. Principle VI. Verification procedures</b>				
1. Were the verification of HACCP system made at established frequency?				
2. Were the verification of HACCP system made in accordance to established verification methods?				
3. Were the verification results analyzed by competent person?				
4. Did the verification results influenced the frequency of verifications?				
5. Did the verification results lead to improvement of HACCP system?				
6. Did persons designated to verification had a relevant authority e.g. auditor's training, proven expertise in HACCP system?				
7. Were preventive and corrective actions taken after verification of HACCP system?				
8. Were developed documentation of HACCP system verified periodically?				
<b>Block 6 Step 12. Principle VII. Recordkeeping and documentation</b>				
1. Was the system documentation available to relevant employees?				
2. Whether the operating documentation was completed by designated employees?				
3. Was the system documentation under appropriate supervision?				
4. Were all amendments in control cards authorized and signed by responsible employees?				
5. Was all system documentation up to date?				
6. Were outdated documents replaced to date in due course?				
7. Did operating records legible and clearly understood?				

The audit questionnaire for data collection was developed in alignment with the Codex Alimentarius Commission's General Principles of Food Hygiene and HACCP System Guidelines [25,26]. The questionnaire contained documentation (Part I: 110 questions) and practical functioning aspects (Part II: 36 questions) of the HACCP system (Table 1). Each company underwent a single audit visit, during which data were collected using direct observation. Each component was scored using a 4-point ordinal scale, where: 2 - non-compliance, 3 - partial compliance, 4 - substantial compliance, and 5 - full compliance. In Part I, the total score ranged from a minimum of 220 to a maximum of 550, while in Part II, the score ranged from a minimum of 72 to a maximum of 180. Scores from individual sections were aggregated and normalized to produce an overall compliance score for each company. This structured scoring approach provided a quantitative basis for statistical analysis of HACCP performance according to company size and product category. The data was then converted into a compliance score and further statistical analysis. The audit was conducted by an experienced professional specializing in food quality management, HACCP system implementation, food hygiene research, and auditing. The auditor's competence was regularly reviewed in accordance with ISO 19011 guidelines [27] and maintained through continuous professional development and training. A four-point grading scale was used to evaluate compliance: A score of 5 indicated full compliance (100%), 4 reflected minor deviations (approximately 80%), 3 represented partial compliance (approximately 60%), and 2 indicated minimal compliance (less than 40%) [24,28]. The scale was intentionally non-centralized, enabling the auditor to exercise professional judgment in assigning scores. Scores of 4 and 5 were considered a pass, while scores of 2 and 3 were classified as non-compliant for documentation and functional aspects. All data collected were anonymized to ensure confidentiality and were used strictly for academic and policy research purposes.

## 2.2. Classification of variables and HACCP compliance scoring

To study the factors influencing HACCP compliance, audited companies were classified according to two key variables: Type of organic product processed and company size, with compliance evaluated using a standard scoring framework. Each company was classified according to its primary organic food product into one of the following five categories: fruits and vegetables, meat and meat products, dairy and dairy products, rice and rice-based products, and ready-to-eat (RTE) Foods. Company size was determined based on annual turnover using thresholds aligned with Indian food industry standards: Small: Turnover less than INR (Indian rupee) 100 crore, medium: Turnover between INR 100–500 crore, and large: Turnover above INR 500 crore [29].

## 2.3. Statistical analysis

All data were analyzed using MS excel R Studio. Descriptive statistics were used to summarize mean scores across groups. To examine how product type and company size jointly influence HACCP compliance, a two-way analysis of variance (ANOVA) was applied separately to Part I (HACCP documentation), Part II (HACCP functioning), and total HACCP scores. This method enabled the identification of major effects as well as any significant interaction effects between the two factors, indicating whether the influence of one variable depends on the level of the other. The Shapiro-Wilk test and Levene's test were used to assess the assumptions of normality and homogeneity of variance before doing ANOVA, and it was discovered that these conditions were sufficiently met for all dependent variables.

Tukey's Honest Significant Difference (HSD) test was employed to test which groups differed significantly in their total HACCP Scores. In addition, cluster analysis was applied to identify natural groupings among companies based on HACCP performance. Finally, Principal Component Analysis (PCA) was used to reduce data dimensionality and identify underlying patterns [30,31]. For the analysis, we focused on understanding how the type of products and the size of the company influence the implementation and functioning of the HACCP system.

## 3. Results

### 3.1. Overview of HACCP performance by company size

Table 2. Findings from a two-way analysis of variance (ANOVA) that looked at how product type, company size, and their combination affected HACCP compliance scores among certified organic food processing businesses in Kerala, India. These scores included HACCP implementation (Part I), HACCP functioning (Part II), and overall HACCP scores. F-values, matching p-values, mean squares, sums of squares, and degrees of freedom (DF) are presented. HACCP compliance varied by product category, company size, and their interaction, according to statistically significant effects ( $p < 0.05$ ) (Table 2). Two-way ANOVA revealed statistically significant effects of product type, company size, and their interaction on HACCP implementation (Part I), HACCP functioning (Part II), and total HACCP compliance scores (Table 2).

**Table 2.** The results of two-way ANOVA assessing the effects of product type, company size, and their interaction on HACCP implementation (Part I), HACCP functioning (Part II), and total HACCP compliance scores.

Part I (HACCP implementation score)					
Groups	DF	Sum of squares	Mean square	F	P-value
Type of products	11	12220.223	1110.929	3.746	<0.001
Company size	2	33165.596	16582.798	55.914	<0.001
Type × size interaction	22	47919.975	2178.181	7.344	<0.001
Part II (HACCP functioning score)					
Groups	DF	Sum of squares	Mean square	F	P-value
Type of products	11	16845.325	1531.393	2.6	0.007
Company size	2	45553.402	22776.701	38.669	<0.001
Type × size interaction	22	68538.852	3115.402	5.289	<0.001
Total HACCP score					
Groups	DF	Sum of squares	Mean square	F	P-value
Type of products	11	123184.709	11198.61	2.841	0.004
Company size	2	346409.321	173204.66	43.94	<0.001
Type × size interaction	22	512998.888	23318.131	5.915	<0.001

A descriptive analysis of HACCP audit scores revealed a clear gradient in compliance based on company size. As shown in Table 3, large enterprises had the highest average scores across all three components of the audit, Part I (HACCP implementation), Part II (HACCP functioning), and the total score, while small enterprises showed the lowest compliance levels.

**Table 3.** Mean and standard deviation of HACCP implementation (Part I), HACCP functioning (Part II), and total scores by company size (big, medium, small).

Company size	n	Part I (mean ± SD)	Part II (mean ± SD)	Total (mean ± SD)	% of conformity
Big	27	473.7 ± 16.4	148.7 ± 10.3	622.4 ± 19.4	85.30%
Medium	44	396.2 ± 32.4	137.2 ± 21.8	533.2 ± 39.1	73.00%
Small	29	325.4 ± 32.0	133.7 ± 26.6	459.1 ± 41.6	62.9%

Subsequent post-hoc pairwise comparison of company sizes (using Tukey's HSD test) confirmed that larger companies outperformed medium and small enterprises in all aspects of HACCP compliance (Table 4). The most significant discrepancies were observed in Part I (documentation), where small businesses struggled to achieve even basic standards like structured hazard analysis and crucial control point identification. These differences suggest that smaller processors' ability to maintain fully functional HACCP systems is limited.

**Table 4.** Tukey's HSD post hoc comparisons of HACCP scores by company size.\*Significant at  $p < 0.05$ .

Comparison	Part I score mean difference (p-value)	Part II score mean difference (p-value)	Total score mean difference (p-value)
Large vs Medium	-43.64* (<0.05)	-58.28* (<0.001)	-156.67* (<0.001)
Large vs Small	40.09* (<0.001)	41.68* (<0.001)	120.66* (<0.001)
Medium vs Small	83.73* (<0.01)	99.96* (0.02)	277.33* (0.03)

### 3.2. Impact of product type and company size on HACCP scores

To evaluate the impact of product type and company size on HACCP compliance, a series of two-way ANOVA tests was conducted for each score category, and the mean difference value between the average scores of the two groups was compared. The asterisk (\*) in the mean values indicates that the difference between the two groups means is statistically significant. For Part I (Documentation), there were statistically significant effects of product type ( $F = 3.75$ ,  $p < 0.001$ ), company size ( $F = 55.91$ ,  $p < 0.001$ ), and a significant interaction effect ( $F = 7.34$ ,  $p < 0.001$ ), indicating that the effect of company size varied depending on the product category. Similar patterns were observed for Part II (functioning), where product type ( $F = 2.60$ ,  $p = 0.007$ ), company size ( $F = 38.67$ ,  $p < 0.001$ ), and interaction ( $F = 5.29$ ,  $p < 0.001$ ) were all significant. For the total HACCP score, all major effects and interactions were significant (product type:  $p = 0.004$ ; company size:  $p < 0.001$ ; interaction:  $p < 0.001$ ).

Companies processing meat and RTE foods recorded higher HACCP compliance scores. In contrast, rice-based and dairy processing units had lower scores. Fruit and vegetable processors showed intermediate performance. Large companies demonstrated the highest levels of HACCP compliance, followed by medium-sized companies, while small enterprises showed the lowest compliance across all assessed areas.

### 3.3. Cluster-based grouping of organic food companies by HACCP performance

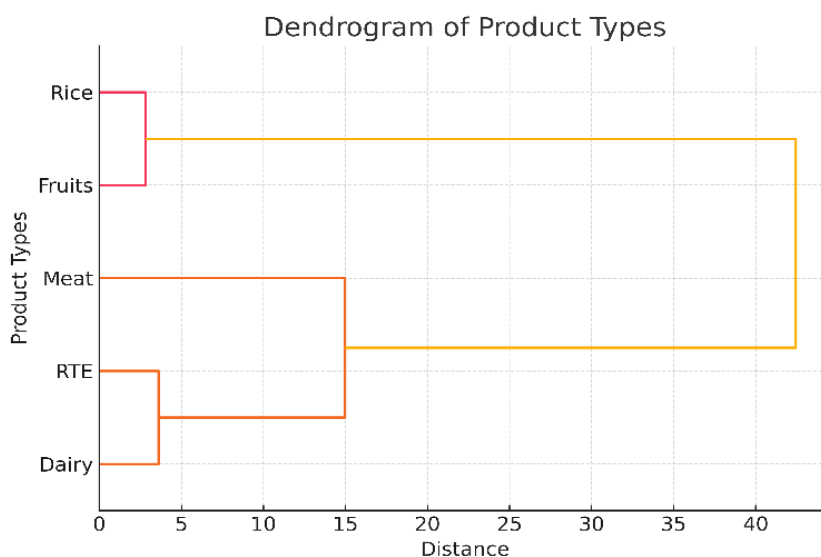
Three separate groups representing high, moderate, and low HACCP compliance levels were formed using hierarchical cluster analysis. Large businesses, especially those that processed meat and ready-to-eat goods, dominated the high-compliance cluster (0). Medium-sized businesses from a variety of product categories made up most of the moderate-compliance cluster (1). Small-scale processors, mostly engaged in rice-based and dairy products, made up most of the low-compliance cluster (2), suggesting ongoing structural constraints in HACCP implementation.

The cluster analysis further reinforced these findings by grouping companies into high, moderate, and low compliance clusters, which closely mirrored differences in company size and product type. High-performing clusters were dominated by large enterprises or those handling export-sensitive commodities, while low-performing clusters were primarily composed of small firms dealing with less regulated products (Table 5).

**Table 5.** Cluster analysis summary.

Cluster	Mean ( Part I Score)	Mean (Part II score)	Mean (Total score)
0	208.8	249.9	687.9
1	165.2	191.6	531.3
2	125.1	149.9	410.6

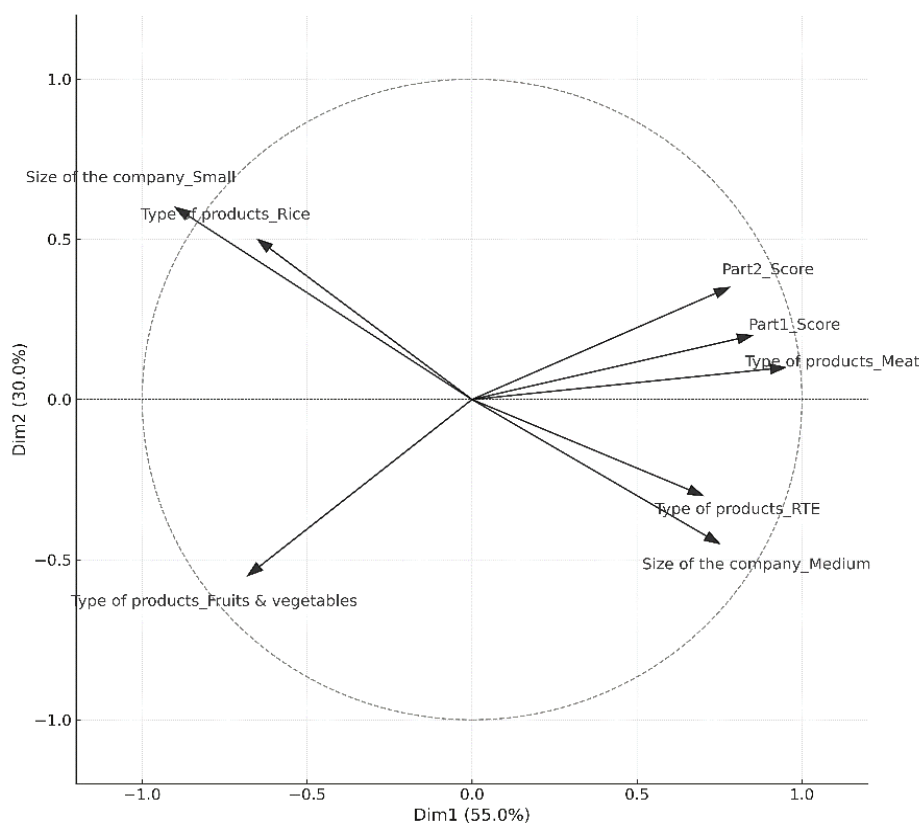
The hierarchical cluster analysis of product categories based on HACCP audit scores resulted in a dendrogram that grouped the five product types into three major clusters (Figure 1). RTE and Dairy products were closely clustered, indicating high similarity in their HACCP compliance scores. Rice and Fruits formed a separate sub-cluster with moderate similarity. Meat products were positioned as a separate cluster at a higher distance from the other groups, indicating lower similarity in HACCP scores compared to the rest. The clustering was based on score patterns from HACCP documentation and functioning components.



**Figure 1.** Hierarchical cluster dendrogram of organic food processing enterprises based on HACCP documentation, functioning, and total compliance scores, identifying three distinct compliance clusters.

#### 3.4. Principal component analysis of HACCP compliance scores

The PCA correlation diagram illustrates the relationships among variables influencing HACCP compliance, including company size, product type, and audit score components. The first two principal components (PC1 and PC2) explained 55.0% and 30.0% of the total variance, respectively, accounting for a combined 85% of the variation in the dataset.



**Figure 2.** PCA biplot illustrating associations between HACCP compliance scores, company size, and product categories among certified organic food processors.

In the diagram (Figure 2), vectors representing Part I score and Part II score are closely aligned, indicating a strong positive correlation between documentation and functioning components of HACCP compliance. The type of product, meat, and the RTE vector are in the positive quadrant near the documentation and functioning scores, indicating that these processors also have a strong HACCP system implementation. The Rice vector lies in the negative Dim1 and positive Dim2 quadrant, which places it opposite the documentation and functioning scores. This implies a negative correlation. The fruits & vegetables vector points in a moderate negative direction on both dimensions, suggesting that performance among these processors is mixed. The vector for small companies lies in the strong negative direction along Dim1, nearly opposite to the documentation and functioning vectors. This suggests that small enterprises consistently score lower on HACCP compliance. The Medium-sized company vector is placed in a positive Dim1 and negative Dim2 quadrant, closer to the origin. This reflects a moderate positive association with HACCP documentation and functioning.

#### 4. Discussion

We set out to understand HACCP compliance in the organic food processing sector in Kerala, India, focusing on how compliance levels vary by company size and product type. The statistical analysis of audit data from 100 certified organic enterprises revealed clear patterns that contribute to the broader understanding of food safety implementation in emerging organic markets.

A primary finding was the consistent relation between company size and HACCP compliance,

with large enterprises showing significantly higher conformity across documentation, system functioning, and total compliance. Similar results were revealed by authors worldwide citing resource availability, technical capacity, and structured management systems as important accelerators of HACCP performance in larger companies [32–35]. Even though the use of HACCP has been extensively researched in the conventional food processing industry, there is an inadequate amount of empirical data that focuses on organic food processing businesses, especially in developing nations. By offering audit-based data that connects HACCP compliance with the structural features of organic processors, our study helps close this gap. Moreover, Large companies have often dedicated food safety teams, formal documentation protocols, and greater exposure to international standards, especially when engaged in export-oriented production [32,36,37]. In contrast, small and medium enterprises, which form the backbone of India's organic sector, tend to operate with limited resources, minimal technical support, and informal management practices, all of which hinder effective HACCP system development and execution [6,38–41]. A study revealed that certified food businesses often failed to maintain full compliance in the functioning of HACCP principles, especially regarding verification procedures, determination of critical control points (CCPs), and corrective actions [38,42–45]. HACCP systems are frequently implemented inconsistently throughout the world, with monitoring, verification, and corrective actions being performed insufficiently. In small and medium-sized businesses, this is made worse by a lack of technical expertise, excessively complicated documentation, and a lack of regulatory support [41,42,46–49].

Other than company size, the type of product processed also plays a decisive role in HACCP outcomes, and some authors have discussed the food safety compliance in fruits and vegetable industries [50–52]. Furthermore, companies engaged in the processing of high-risk foods such as meat and RTE products recorded higher compliance scores. Many incidents of food safety-related issues in RTE products have been discussed by authors from different countries [53–57]. These products, due to their susceptibility to microbial contamination and perishability, are subject to stricter food safety regulations and are often more aligned with international trade requirements [8,23,33,58,59]. On the other hand, processors of rice-based and dairy products, particularly at smaller scales, were found to have relatively lower levels of compliance [60–63]. These product categories are commonly associated with minimal processing or traditional methods and are often handled by smaller facilities with limited access to food safety expertise and oversight [61,64,65].

Interestingly, we found a significant interaction effect between company size and product type, indicating that the impact of size on HACCP performance is not uniform across product categories [59]. This suggests that the hazard profile of the product may amplify the structural limitations of smaller enterprises, making it more difficult for them to meet compliance standards in high-risk categories [36]. Moreover, researchers [18–20] have identified significant knowledge gaps among organic food company operators in selected EU nations about the principles and execution of HACCP systems, particularly in terms of documentation and hazard analysis. Although enhancing HACCP implementation in underdeveloped countries faces considerable challenges, such as inadequate regulatory infrastructure, insufficient technical knowledge, and low hygiene awareness, this difficulty also presents a significant opportunity [48,49]. Furthermore, as the global demand for organic food continues to rise [66–68], and taking advantage of this popularity, developing nations can enhance food safety and public health, and position themselves competitively in growing global organic markets.

This work makes a novel scientific contribution by conducting structured HACCP audits on a large, diversified sample of certified organic food processors in India, an area with relatively little research. Most HACCP studies either focus on conventional food sectors or individual commodities, with little emphasis given to organic systems, despite their growing importance in India's food landscape. Most researchers focus on conventional food systems, with limited attention given to the unique challenges of organic processing in developing countries. By linking audit outcomes with structural characteristics such as size and product category, this research contributes to a more detailed understanding of how food safety systems operate in resource-constrained and diverse production environments. Despite its valuable insights, this study has certain limitations: The sample was limited to 100 organic food processing units in Kerala, which may not fully represent the broader national landscape. Additionally, audits were conducted by a single trained auditor; despite adherence to standardized Codex-aligned criteria, the employment of a single auditor may create subjective bias, even though this maintained consistency in audit application and scoring.

## 5. Conclusions

In this study, we include an in-depth assessment of the HACCP system in certified organic food processing enterprises in Kerala, India using a structured audit tool aligned with Codex Alimentarius principles. We statistically analyzed multiple product categories and business sizes. The findings showed that HACCP compliance varies across the organic industry and is heavily influenced by the type of product processed and the size of the company.

High-risk product categories, such as meat and RTE products, had comparatively higher compliance scores, particularly among larger enterprises. This can be described as increased regulatory scrutiny, export market demands, and resource availability for system adoption. In contrast, poorer compliance levels were reported in rice-based and dairy processing units, particularly among small businesses, with significant nonconformities in hazard identification, documentation methods, and corrective action procedures.

The use of advanced statistical tools enabled in-depth interpretation of the patterns and interactions within the dataset. This study contributes to the food safety literature as one of the first to thoroughly analyze HACCP compliance in India's organic processing sector, which is rapidly growing but under-researched. The findings highlight the critical need to incorporate HACCP principles into organic certification methods to ensure that environmental and public health goals are addressed.

The findings offer policymakers some insight into promoting the development of tailored training programs, particularly for small-scale organic processors handling high-risk commodities. Certification bodies and government agencies (such as FSSAI, APEDA, and PGS-India) may benefit from introducing risk-based audits and capacity-building workshops to increase compliance. Furthermore, improving HACCP implementation in the organic industry will raise consumer confidence in domestic markets while increasing India's competitiveness in the international organic market.

### Use of AI tools declaration

The authors declare they have not used Artificial Intelligence (AI) tools in the creation of this article.

## Conflict of interest

The authors declare that they have no conflicts of interest.

## Author contributions

Conceptualization, A.P.M. and J.T.; methodology, A.P.M.; software, A.P.M.; validation, J.T. and S.S.N.; formal analysis, A.P.M.; investigation, A.P.M.; resources, A.P.M.; data curation, A.P.M.; writing- original draft preparation, A.P.M.; writing-review and editing, J.T.; visualization, A.P.M.; supervision, J.T.

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