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Prioritizing Food Safety Culture Multicriteria Dimensions: An Approach Using Analytic Hierarchy Process (AHP)

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A B S T R A C T

Food safety management systems are widely certified, yet foodborne illness and product recalls are still traced to human and organizational factors, which makes food safety culture (FSC) a priority for food manufacturers. Existing FSC frameworks describe and measure culture but do not show which dimensions should be strengthened first when resources are limited. This study applies the Analytic Hierarchy Process (AHP), a multicriteria decision-making method, to prioritize the five dimensions of food safety culture (FSC) and their 16 sub-criteria at PT XYZ, an Indonesian food manufacturer. Ten experts from quality assurance, production and consulting completed 28 pairwise comparisons; all judgement matrices met the consistency threshold (CR ≤ 0.10), judgements were aggregated by geometric mean, and agreement was tested with Kendall's W. Company Values, Vision and Mission ranked first (31.11%), followed by People (22.69%), Consistency for Food Safety (20.88%), Hazard and Risk Awareness (17.07%) and Adaptability, Change and Continuous Improvement (8.25%). The five highest-weighted sub-criteria together carried 57.24% of the total weight. The production team ranked People first, whereas QA/QC and consultants ranked Values first, and overall agreement was moderate and significant ($W = 0.520$, $p < 0.001$). The findings support a foundation-first sequence that begins with values, leadership and accountability. The study can serve as a complementary option for FSC research, moving it from descriptive assessment to prescriptive prioritization and offers food manufacturers a replicable, weighted improvement roadmap.

KATA KUNCI

Budaya Keamanan Pangan, *Analytic Hierarchy Process*, Pengambilan Keputusan Multikriteria, Prioritisasi Dimensi, Industri Pangan

A B S T R A K

Sistem manajemen keamanan pangan telah banyak tersertifikasi, tetapi penyakit bawaan pangan dan penarikan produk masih bersumber dari faktor manusia dan organisasi, sehingga budaya keamanan pangan (*food safety culture*/FSC) menjadi prioritas bagi industri pangan. Kerangka FSC yang ada mendeskripsikan dan mengukur budaya, tetapi belum menunjukkan dimensi mana yang perlu diperkuat lebih dahulu ketika sumber daya terbatas. Penelitian ini menerapkan metode pengambilan keputusan multikriteria *Analytic Hierarchy Process* (AHP) untuk memprioritaskan lima dimensi budaya keamanan pangan beserta 16 subkriteria di PT XYZ, perusahaan pangan di Indonesia. Sepuluh pakar dari bidang penjaminan mutu, produksi, dan konsultan mengisi 28 perbandingan berpasangan; seluruh matriks penilaian memenuhi batas konsistensi (CR ≤ 0,10), penilaian diagregasi dengan rata-rata geometrik, dan kesepakatan pakar diuji dengan Kendall's W. *Company Values, Vision and Mission* menempati peringkat pertama (31,11%), diikuti *People* (22,69%), *Consistency for Food Safety* (20,88%), *Hazard and Risk Awareness* (17,07%), serta *Adaptability, Change and Continuous Improvement* (8,25%). Lima subkriteria dengan bobot tertinggi mencakup 57,24% dari total bobot. Tim produksi menempatkan *People* di peringkat pertama, sedangkan QA/QC dan konsultan menempatkan *Values* di peringkat pertama, dengan tingkat kesepakatan sedang dan signifikan ($W = 0,520$; $p < 0,001$). Temuan ini mendukung urutan perbaikan yang dimulai dari fondasi, yaitu nilai, kepemimpinan, dan akuntabilitas. Penelitian ini dapat menjadi opsi pelengkap kajian FSC dari penilaian deskriptif menuju prioritisasi preskriptif dan menawarkan peta jalan perbaikan berbobot yang dapat direplikasi.

1. Introduction

1.1. Research Background

Food safety in food manufacturing is, at its core, a question of human behaviour [1], [2]. Contaminated food was estimated to cause about 600 million cases of foodborne disease worldwide [3], and the productivity losses it causes in low- and middle-income countries are estimated at US$95.2 billion per year [4]. Every food safety management system therefore contains an implicit assumption about how consistently people will follow it, and the system is only as reliable as that

behaviour [1], [5]. Recall data show that these behavioural failures persist even in highly regulated markets [5]. An analysis of 35,548 food recall incidents in the United States between 2002 and 2023 identified biological contamination (48%), allergens (28%) and foreign objects (7%) as the leading causes, and the authors attributed at least 75% of these recalls directly to human error [5]. Labelling errors are likewise a recurring source of food recalls and alerts worldwide [6].

Indonesia adds further structural pressure [7]. By the end of 2025, the national free school meals programme had been linked to 177 food poisoning outbreaks affecting more than 20,000 schoolchildren across 33 provinces, prompting calls for embedding food safety principles and mandatory compliance monitoring across the food supply chain [7]. National values and food safety governance also appear to influence the food safety culture that develops inside companies [8].

Food manufacturers have responded mainly through formal food safety management systems (FSMS) built on prerequisite programmes, Hazard Analysis and Critical Control Points (HACCP) and certifiable schemes such as ISO 22000 and FSSC 22000 [9], [10]. These systems have raised the technical baseline, yet failures continue to be traced to what people believe, prioritize and actually do rather than to the absence of written procedures [1], [2]. This recognition gave rise to food safety culture (FSC), the shared values, beliefs and norms that shape how people in an organization think about and behave towards food safety [1], [11].

The concept has since moved from academic debate into regulation and certification [10], [12]. The Codex Alimentarius Commission revised its General Principles of Food Hygiene (CXC 1-1969) in 2020 to include FSC, and certification schemes now assess leadership commitment, communication, training and employee engagement [10]. Regulators are likewise developing maturity frameworks for their own food safety practice [12]. The Global Food Safety Initiative (GFSI) arranges FSC in its 2026 update as a wheel of five interacting dimensions, in which Company Values, Vision and Mission and People: Commitment, Empowerment and Accountability form the organizational foundation for Hazard and Risk Awareness, Consistency for Food Safety and Adaptability, Change and Continuous Improvement [13].

Many processed foods, such as dry seasonings, powdered ingredients and instant products, are low-moisture, multi-ingredient products [14]. This category has been implicated in foodborne outbreaks, most often caused by *Salmonella*, which, together with other pathogens, can remain viable in dry products for months or even years [14]. Product safety in such operations therefore depends on whether hygiene, allergen, labelling and foreign-matter controls are applied consistently across time, roles and operational settings, which is the role that GFSI assigns to its Consistency for Food Safety dimension [5], [13].

PT XYZ is an Indonesian food manufacturer with a certified food safety management system, under which food safety culture must be assessed and improved. Like other food manufacturers that supply modern retail and food service, it is increasingly expected to demonstrate a managed and improving food safety culture rather than only a documented FSMS [10], [13]. Strengthening that culture, however, requires investment, since companies with more mature FSC tended to spend more on prevention and appraisal activities in a pilot study [15]. Perceptions of FSC also differ between employee groups within the same company, so the functions that would guide such investment cannot be assumed to share the same priorities [16].

The gap between the many elements of FSC and the limited resources available to strengthen them is therefore the central managerial problem of this study [10], [15]. An operational understanding of how to assess, align and systematically improve FSC is still limited, which leaves managers without an evidence-based basis for sequencing improvement efforts [10]. Solving this problem requires two bodies of knowledge that are rarely used together, namely FSC research and multicriteria decision-making [11], [17], which are reviewed briefly below.

1.2. Food Safety Culture: From Management Systems to Shared Behaviour

FSC research has produced many models and assessment tools whose dimensions and definitions differ substantially [11]. A recent synthesis reduced these constructs to five common denominators, namely leadership, knowledge and awareness, communication, commitment and responsibility, and continuous improvement, while noting that individual models still use their own overarching terms [10]. Four strands of this literature frame the present study.

From compliance to culture. Formal FSMS such as HACCP, ISO 22000 and FSSC 22000 define what should be done, but their adoption depends on effective management, adequate personnel training and staff commitment [9]. Recall evidence attributes most failures to human error [5], which is why the Codex General Principles of Food Hygiene and certification schemes now address FSC explicitly [10].

Culture versus climate. Food safety culture refers to the relatively stable values, beliefs and norms shared within an organization, while food safety climate refers to employees' current perceptions of food safety policies and practices [1]. Climate is therefore the more accessible indicator, and many survey instruments measure it as a window on the underlying culture [1], [18].

Assessment approaches. A mixed-methods systematic review shows that FSC assessment has evolved into a diverse set of methods whose instruments differ in the dimensions they include and how they define them [11]. Maturity-based approaches classify companies as reactive, active or proactive, and even certified manufacturers can score only "reactive" on risk perception [8], [19].

Contextual drivers. Culture profiles differ between countries with different national values and governance arrangements [8], and leadership style and multicultural workforces shape how culture forms within firms [2]. FSC elements are also interdependent, as leadership influences commitment indirectly through communication, management systems and the work environment [20]. Perceptions vary inside companies with role, training and seniority, although the direction is not uniform: managers and regularly trained staff rated FSC more favourably in one study [18], while longer-serving employees gave lower ratings in several areas in another [16].

1.3. GFSI Dimensions of Food Safety Culture and Their Sub-Criteria

The 2026 GFSI position paper retains five dimensions and arranges them as a wheel in which two organizational foundations support three manifested essentials [13]. This study operationalizes each dimension through three or four sub-criteria drawn from the literature, as summarised in Table 1 [10], [13].

Table 1. AHP Hierarchy: Dimensions, Sub-Criteria and Supporting Literature

Dimension (criterion)	Sub-criterion	Operational definition	Supporting literature
D1 Company Values, Vision and Mission	D1.1 Vision & values	Food safety is explicit in the vision, values and strategic objectives	[2], [13]
	D1.2 Leadership commitment	Managers visibly prioritize food safety, allocate resources and role-model behaviour	[2], [10], [20]
	D1.3 Communication of expectations	Goals and changes are communicated clearly, consistently and two-way	[10], [20]
D2 People: Commitment, Empowerment and Accountability	D2.1 Accountability & ownership	Roles are clearly defined and individuals own food safety outcomes	[9], [10]
	D2.2 Recognition & empowerment	Safe behaviour is recognized and employees may stop work when food safety is at risk	[2], [13]
	D2.3 Teamwork & coordination	Departments, teams and shifts coordinate to achieve food safety objectives	[2], [20]
	D2.4 Behaviour & attitude	Employees hold positive attitudes and practise safe handling consistently	[19], [21]
D3 Hazard and Risk Awareness	D3.1 Risk awareness & perception	Employees correctly perceive the hazards linked to their own tasks	[8], [19]
	D3.2 Training & knowledge	Competence is built through relevant, effective and current training	[9], [18], [21]
	D3.3 Hazard reporting & speaking up	Hazards, near-misses and non-conformities are reported without fear of blame	[13], [18]
D4 Consistency for Food Safety	D4.1 FSMS implementation	HACCP, ISO 22000 or FSSC 22000 is documented, implemented and verified	[9], [10]
	D4.2 Work pressure & resource adequacy	Time, staffing and targets allow procedures to be followed	[9], [18]
	D4.3 Work environment & infrastructure	Facilities and equipment make compliance practical	[9], [20]
D5 Adaptability, Change and Continuous Improvement	D5.1 Responsiveness to change	New hazards, regulations and customer requirements are anticipated and adopted	[12], [13]
	D5.2 Continuous improvement	Audits, KPIs and verification data are used to improve performance	[10], [15], [18]
	D5.3 Learning from incidents & complaints	Incidents and complaints are analysed for root causes and lessons are shared	[5], [6]

D1 Company values, vision and mission. Food safety culture begins with what an organization declares it stands for and how leaders translate this into direction [2], [13]. Leadership influences employee commitment indirectly through communication, management systems and the work environment [20], and leadership and communication are both among the common denominators of FSC models [10]. Recent reviews link transformational leadership in particular to stronger food safety cultures [2].

D2 People: commitment, empowerment and accountability. Commitment and responsibility form one of the five common denominators of FSC models [10], and commitment is the outcome through which leadership, communication and the work environment act [20]. Commitment is not evenly distributed, as younger food handlers in certified companies reported lower commitment than older colleagues [19]. Attitudes and behaviour are also harder to change than knowledge, since training produced large gains in knowledge but only small gains in attitudes [21].

D3 Hazard and risk awareness. Risk perception is a recurring weak point, as food handlers in certified companies showed an optimistic bias about foodborne

illness risk [19] and all national cultural dimensions were correlated with risk perceptions across four countries [8]. Knowledge and awareness are a common denominator of FSC models [10], and training improves knowledge strongly but observed practices less [21]. Mechanisms that encourage the reporting of critical issues without fear of repercussions are listed among the practices that put FSC into effect, although that study did not measure reporting behaviour directly [18].

D4 Consistency for food safety. Consistency refers to the stability and uniformity of food safety behaviours and decisions across time, roles and operational settings [13]. Barriers to HACCP adoption include ineffective management, inadequate training and a lack of physical conditions [9], and resources were the weakest-rated FSC dimension among food business workers in Southern Italy [18]. The work environment also mediates the effect of leadership on commitment [20], and low-moisture, multi-ingredient processes are particularly sensitive to lapses in hygiene and process control [14].

D5 Adaptability, change and continuous improvement. Continuous improvement is the fifth common denominator of FSC models [10], and FSC is described as grounded in a continuous cycle of review and improvement [18]. Learning from incidents and complaints is supported by recall analyses that reveal recurring causes such as pathogens, allergens and labelling errors [5], [6]. Companies with more mature FSC also tended to spend more on prevention and appraisal [15], and regulators are adopting maturity frameworks that make improvement over time explicit [12].

1.4. Multicriteria Decision-Making and the Analytic Hierarchy Process

Prioritizing FSC dimensions is a multicriteria problem because the criteria are qualitative, interdependent and perceived differently by different groups of employees [16], [20]. The Analytic Hierarchy Process (AHP) has become one of the most widely applied multicriteria methods over the past four decades [17]. It structures a goal into a hierarchy, compares elements pairwise on a ratio scale and converts these judgements into priority weights [17], [22]. Four features make AHP suitable for this problem, while one limitation shapes how the hierarchy is built.

Consistency of judgement. Each expert's comparison matrix is tested with the consistency ratio, and judgements are accepted when it does not exceed 0.10 [23]. Alternative thresholds for the consistency ratio and the geometric consistency index have also been proposed, so the consistency rule is an explicit methodological choice that must be reported [24].

Group judgement. When several experts are involved, their matrices must be combined. The compatibility of their judgements also becomes a methodological concern in its own right [25].

Applications in food safety. Fuzzy AHP has weighted barriers to food safety standards in a developing-country seafood sector and identified manager commitment, employee resistance and limited firm capacity as the main barriers [26]. DEMATEL has identified ineffective management and inadequate personnel training as the key barriers to HACCP adoption [9], and AHP with a panel of ten academic experts has prioritized sustainability-reporting criteria in pasta production [22].

Independence assumption. AHP assumes that elements at the same level are independent, whereas FSC elements influence one another [20]. This study therefore assigns each sub-criterion to one dimension only and leaves interdependence-based methods, such as those used for HACCP barriers, to future research [9], [20].

1.4. Research Gap

Table 2 summarises the empirical studies closest to this paper, ordered from the most recent [18], [20], [22]. FSC studies describe and measure culture without weighting its dimensions [10], [11], while multicriteria studies in the food sector concentrate on system adoption, barriers and sustainability rather than on culture [9], [22], [26].

Three gaps emerge from this synthesis. First, a prioritization gap: FSC studies define, measure and correlate dimensions but do not weight them, so managers lack an evidence-based basis for sequencing improvement [10], [11], [20]. Second, a methodological gap: expert-based multicriteria studies in food safety address system adoption, barriers and sustainability reporting rather than the dimensions of culture [9], [22], [26]. Third, a contextual gap: the FSC studies reviewed here come mainly from Europe, Latin America, Africa & China [8], [18], [20]. To the best of our knowledge, no prior study has used AHP to weight the GFSI food safety culture dimensions and their sub-criteria in an Indonesian food manufacturer [11], [13].

Table 2. Selected Empirical Studies

Study	Context and data	Methods	Main finding	Link to this study
da Cunha et al. (2025) [20]	471 food handlers, 37 food service units, Brazil	Survey; serial mediation model	Leadership affects commitment through communication, management systems and work environment	FSC elements interdependent; no weighting
Marzocca et al. (2025) [18]	216 workers, 52 food businesses, Italy	Cross-sectional climate survey	Risk awareness strongest, resources weakest; training and role shape perceptions	Dimensions differ; no priority weights
Forte et al. (2024) [19]	Two certified food manufacturers, Italy	FSC pillars and locus of control	Mostly active or proactive, but risk perception reactive and optimistic bias present	Certification does not guarantee mature culture
Spagnoli et al. (2024) [15]	Five food processing companies, Belgium	FSC maturity vs cost of quality	More mature FSC tended to coincide with higher prevention and appraisal costs (pilot study)	Culture needs investment, hence prioritization
Dima et al. (2024) [9]	HACCP adoption, meat industry, 18 experts	DEMATEL	Ineffective management is the top barrier; training is the key cause	Expert MCDM on systems, not culture
Yadav et al. (2024) [26]	Seafood sector, India	Fuzzy AHP–TOPSIS	Manager commitment, employee resistance and firm capacity are the main barriers	AHP in food safety; barriers, not FSC
DeBeer et al. (2024) [5]	35,548 US recall incidents, 2002–2023	Recall database analysis	At least 75% of recalls attributed to human error	Behavioural root of failures
Marconi et al. (2023) [16]	Three food companies, Italy	Employee perception questionnaire	Risk awareness rated highest; lower ratings among longer-serving staff	Perceptions vary by employee group
D'Adamo (2023) [22]	Pasta production, 10 academic experts	AHP	Sustainability-reporting criteria prioritized by expert judgement	Expert-panel AHP in food industry
Nyarugwe et al. (2020) [8]	17 companies in Greece, Zambia, China, Tanzania	FSC assessment and national values	Culture profiles differ by country; national cultural dimensions correlate with risk perception	Context matters; little South-East Asian evidence
Insfran-Rivarola et al. (2020) [21]	Studies of food handler training	Systematic review and meta-analysis	Large effect on knowledge, small effect on attitudes	Knowledge does not ensure behaviour

1.5. Research Purpose, Questions and Propositions

This study fills that gap by prioritizing the FSC dimensions of PT XYZ through structured expert judgement, following the multi-expert AHP approach applied in earlier food-industry studies [22], [26]. The hierarchy comprises the five GFSI dimensions as criteria and 16 sub-criteria, each assigned to a single dimension [13], and pairwise judgements are elicited from quality assurance, production and consultant experts whose perspectives on FSC are expected to differ [2], [16].

Three research questions guide the analysis, following the structure of the GFSI model [13]. RQ1 asks how the five FSC dimensions rank in relative priority for PT XYZ, measured by group priority weights derived from judgement matrices with a consistency ratio of 0.10 or less [23]. RQ2 asks which of the 16 sub-criteria carry the highest global weights and should therefore be targeted first in PT XYZ's FSC improvement programme [10]. RQ3 asks whether these priorities differ between quality assurance, production and consultant experts and how strongly the experts agree on the resulting ranking, measured by Kendall's coefficient of concordance [16].

Figure 1 brings the reviewed literature into one research design. The upper part shows the AHP hierarchy, in which the five GFSI dimensions form Level 1 and the 16 sub-criteria of Table 1 form Level 2 [13]. The lower part shows the analysis procedure, from expert pairwise comparisons and the consistency test to group aggregation and the agreement test that answer RQ1 to RQ3 [22], [25].

Three propositions are tested:

a. P1: the foundation dimensions, D1 and D2, receive higher priority weights than the manifested dimensions D3 to D5, because GFSI positions them as the base of the wheel [13] and leadership acts on commitment through the other elements [20].

b. P2: sub-criteria related to leadership and management commitment carry higher global weights than those related to knowledge and training, because ineffective management is the leading barrier to HACCP adoption [9], manager commitment is a main barrier to standards implementation [26], and training improves knowledge more than practice [21].

c. P3: priorities differ across expert functions, yet the panel shows statistically significant agreement on the overall ranking, because FSC perceptions vary with role and seniority [16], [18] while the GFSI dimensions provide a shared frame of reference [13].

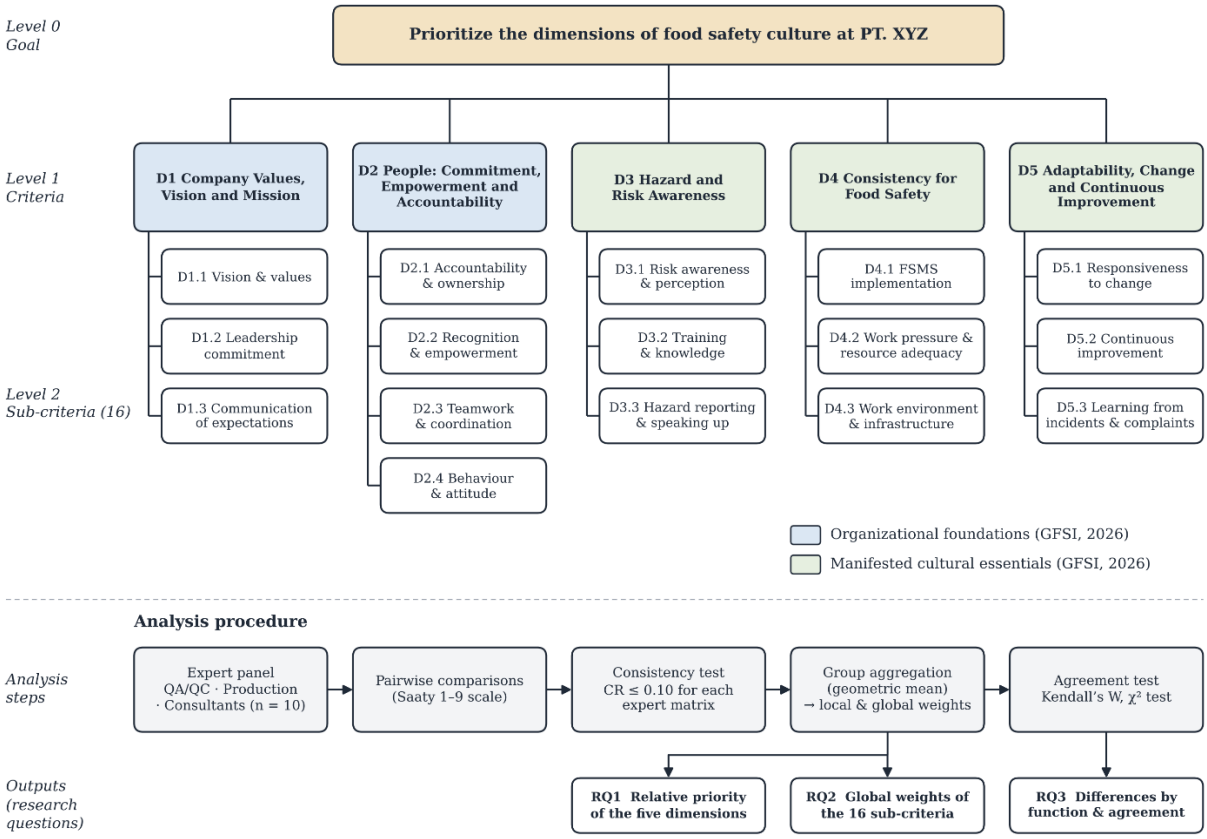


Figure 1. Conceptual Framework: AHP Hierarchy of Food Safety Culture Dimensions and Analysis Procedure

The study offers three contributions. Theoretically, it moves FSC research from descriptive assessment towards prescriptive prioritization and tests whether the foundation dimensions of the GFSI model outweigh the manifested dimensions [11], [13]. Methodologically, it offers a transparent, consistency-checked AHP hierarchy with an explicit test of inter-expert agreement that other food manufacturers can replicate [17], [22]. Practically, it gives PT XYZ and similar firms in emerging markets an evidence-based roadmap for allocating limited resources to the FSC elements most likely to sustain consistent food safety behaviour [10], [15].

2. Research Method

2.1. Research Design and Procedure

This study adopts a quantitative, single-case, expert-based multicriteria design [17], [22]. PT XYZ is treated as an embedded case of an Indonesian food manufacturer whose food safety culture improvement priorities can be derived from the structured judgements of its own specialists and external advisers [10], [13]. A single-case design suits the research questions because they concern one firm's allocation of improvement effort, and the expert judgements required are not available from public sources. The procedure follows the analysis strand of Figure 1 and consists of four stages [23], [27]:

a. Hierarchy development. The five GFSI dimensions and their 16 sub-criteria (Table 1) are arranged in a three-level hierarchy, with each sub-criterion assigned to exactly one dimension [13], [23].

b. Data collection. Ten experts complete a pairwise comparison questionnaire covering the five dimensions and the five sub-criterion clusters.

c. Priority derivation and consistency testing (RQ1, RQ2). Local weights are derived for each expert and each matrix, and every matrix is tested against the consistency threshold [23].

d. Aggregation, global weights and agreement analysis (RQ2, RQ3). Individual judgements are aggregated into group priorities, global weights are calculated for the 16 sub-criteria, and inter-expert agreement is tested with Kendall's W [27], [28].

2.2. Case Setting and Expert Panel

PT XYZ is an Indonesian food manufacturer. This manufacturer profile makes consistent hygiene, allergen, labelling and foreign-matter control a central food safety requirement [5], [6]. Experts were selected by purposive sampling, because AHP relies on informed judgement rather than statistical representativeness [23]. The inclusion criterion was at least five years of experience in food safety, quality assurance, production or food safety consulting, because perceptions of food safety culture vary with seniority [16]. The panel

deliberately combines internal and external perspectives, because perceptions of food safety culture differ between employee groups [16], [18]. Table 3 summarises the panel, whose size is comparable to earlier expert-panel AHP studies in the food industry [22].

Table 3. Profile of the Expert Panel

Function	Experts	n	Experience (years)	Perspective contributed
QA/QC team	E1–E4	4	5–10	Verification, audits and certification requirements
Production team	E5–E8	4	5–10	Shop-floor execution, shifts and operator behaviour
Consultants	E9–E10	2	10–15	Cross-company benchmarks and certification practice
Total		10		

2.3. Research Instrument

Data were collected with a two-part questionnaire. Section I recorded the expert profile, including function and years of experience, together with informed consent. Section II contained the pairwise comparisons, framed by the guiding question: "In the context of strengthening food safety culture in food manufacturing companies in Indonesia, which of the two elements is more important, and how much more important is it?"

Section II comprised 28 pairwise comparisons: 10 between the five dimensions and 18 within the sub-criterion clusters (3 each for D1, D3, D4 and D5, and 6 for D2), which took about 20–25 minutes to complete. Each sub-criterion cluster contains at least three elements, because a two-element matrix is always perfectly consistent and therefore provides no evidence of judgemental consistency [23], [24]. Judgements were recorded on Saaty's fundamental 1–9 scale, which can be seen on Table 4, with the reciprocal value entered when the right-hand element was preferred [23].

Table 4. Saaty's Fundamental Scale for Pairwise Comparison [23]

Intensity	Definition	Explanation
1	Equal importance	Both elements contribute equally to the goal
3	Moderate importance	Experience and judgement slightly favour one element
5	Strong importance	Experience and judgement strongly favour one element
7	Very strong importance	One element is very strongly favoured and its dominance is demonstrated in practice
9	Extreme importance	The evidence favouring one element is of the highest possible order
2, 4, 6, 8	Intermediate values	Used when a compromise between adjacent judgements is needed

2.4. Priority Weights and Consistency

For each matrix, the judgements form a positive reciprocal matrix $A = [a_{ij}]$ of order n, in which $a_{ji} = 1/a_{ij}$ and $a_{ii} = 1$ [23]. Local priority weights are derived with the row geometric mean method, as presented in Equation (1), where w_i is the local priority weight of element i, a_{ij} is the judgement comparing element i with element j, and n is the number of elements in the matrix [23], [25].

$$w_i = \frac{\left(\prod_{j=1}^{n} a_{ij}\right)^{1/n}}{\sum_{k=1}^{n}\left(\prod_{j=1}^{n} a_{kj}\right)^{1/n}} \quad (1)$$

The principal eigenvalue is approximated from the column totals and the derived weights, and it is used to calculate the consistency index (CI) and the consistency ratio (CR) in Equations (2) and (3), where λ_{max} is the approximated principal eigenvalue, CI is the consistency index, and RI is the random index [23].

$$\lambda_{max} = \sum_{j=1}^{n}\left(\sum_{i=1}^{n} a_{ij}\right) w_j \quad (2)$$

$$\mathrm{CI} = (\lambda_{max} - n)/(n-1), \quad \mathrm{CR} = \mathrm{CI}/\mathrm{RI} \quad (3)$$

Only matrices with $\mathrm{CR} \leq 0.10$ are included in the analysis [23]. Because alternative thresholds and consistency indices exist, the consistency rule and the approximation of λ_{max} used here are reported explicitly [24]. Each expert contributes six matrices, one for the dimensions and one for each sub-criterion cluster, so 60 matrices are tested in total.

2.5. Group Aggregation and Global Weights

Individual judgements are aggregated with the aggregation of individual judgements (AIJ) approach, which combines the experts' entries cell by cell with the geometric mean in Equation (4), where a_{ij}^{G} is the group judgement, $a_{ij}^{(k)}$ is the judgement of expert k, and m = 10 is the number of experts[27].

$$a_{ij}^{G} = \left(\prod_{k=1}^{m} a_{ij}^{(k)}\right)^{1/m} \quad (4)$$

The geometric mean preserves the reciprocal property of the group matrix, which is why it is the appropriate operator when a panel acts as a single decision unit [27]. Group weights and the group CR are then derived from the aggregated matrix with Equations (1) to (3) [23]. The aggregation of individual priorities (AIP), the normalized geometric mean of each expert's weights, is also computed. With the row geometric mean method, the two approaches are mathematically equivalent, so their agreement verifies the calculations rather than testing robustness [25], [27]. The global weight of each sub-criterion is calculated with Equation (5), where GW_s is the global weight of sub-criterion s, w_d is the group weight of its parent dimension d, and $w_{s|d}$ is the local weight of s within d [23].

$$GW_s = w_d \times w_{s|d} \quad (5)$$

To answer the first part of RQ3, group weights are also calculated separately for the quality assurance, production and consultant groups as the normalized geometric mean of their members' individual weights

[27]. These group-level profiles are compared descriptively, because the subgroups are too small for inferential testing.

2.6. Inter-Expert Agreement

The second part of RQ3 is answered with Kendall's coefficient of concordance (W), which measures how far the experts agree on the rank order of the elements [28], [29]. Each expert's local weights are converted into ranks, with tied ranks averaged, and W is calculated with the tie correction in Equation (6), where S is the sum of squared deviations of the rank totals from their mean, m is the number of experts, n is the number of elements, and t is the number of observations in each group of ties [28].

$$W = 12S / [m^2(n^3 - n) - m \sum T], \quad T = \sum(t^3 - t) \qquad (6)$$

The significance of W is tested with $\chi^2 = m(n - 1)W$ with $n - 1$ degrees of freedom at $\alpha = 0.05$ [28], [29]. W is interpreted with Schmidt's thresholds, in which values of about 0.1, 0.3, 0.5, 0.7 and 0.9 indicate very weak, weak, moderate, strong and unusually strong agreement, respectively [29]. Agreement is tested for the dimension level and separately for each of the five sub-criterion clusters.

2.7. Link Between Research Questions, Propositions and Analysis

Table 5 links each research question and proposition to its analysis and decision rule, and the rules were fixed before the results were examined. All calculations were performed in a Microsoft Excel workbook developed for this study, in which every matrix, weight, consistency ratio and concordance statistic is computed by formula from the raw judgements. Because AIJ and AIP are mathematically equivalent under the row geometric mean method, the two results serve as a cross-check of the calculations [25], [27]. Combining judgements with the geometric mean also cancels out small random inconsistencies between individual experts, so group matrices are expected to be more consistent than individual ones [27]. Participation was voluntary, responses are reported only in aggregated form, and the company is anonymized as PT XYZ.

Table 5. Research Questions, Propositions, Analyses and Decision Rules

RQ / proposition	Question	Analysis	Decision rule
RQ1 / P1	Relative priority of the five dimensions	AIJ group weights of D1–D5; group CR	P1 supported if the weights of D1 and D2 both exceed those of D3, D4 and D5, with group CR ≤ 0.10
RQ2 / P2	Global weights of the 16 sub-criteria	Global weights (Eq. 5); cluster CRs	P2 supported if the global weight of D1.2 Leadership commitment exceeds that of D3.2 Training & knowledge
RQ3 / P3	Differences by expert function and agreement	Function-group weights; Kendall's W and χ^2 test	P3 supported if the top-ranked dimension or rank order differs between functions and W is significant at $\alpha = 0.05$

3. Results and Discussion

3.1. Consistency of Expert Judgements

All 60 comparison matrices met the consistency threshold of CR ≤ 0.10, which means that every expert answered the pairwise comparisons in a logically consistent way [23]. For the five dimensions, the experts' individual CRs ranged from 0.016 to 0.079, and across the 50 sub-criterion matrices the highest CR was 0.099, still below the limit. When the judgements of the ten experts were combined, the group results were more consistent, with CR = 0.009 for the dimensions and between 0.004 and 0.017 for the five sub-criterion clusters. The AIJ and AIP approaches gave identical group weights.

3.2. Priority of Food Safety Culture Dimensions (RQ1)

Table 6 presents the aggregated pairwise comparison matrix for the five dimensions. The experts judged Company Values, Vision and Mission (D1) to be about twice as important as Hazard and Risk Awareness (D3) and about 4.5 times as important as Adaptability, Change and Continuous Improvement (D5).

Table 6. Aggregated Pairwise Comparison Matrix of the Five Dimensions (AIJ)

Dim.	D1	D2	D3	D4	D5	Weight
D1	1.000	1.116	2.024	1.374	4.525	31.11%
D2	0.896	1.000	1.246	0.896	2.896	22.69%
D3	0.494	0.803	1.000	0.836	2.107	17.07%
D4	0.728	1.116	1.196	1.000	1.966	20.88%
D5	0.221	0.345	0.475	0.509	1.000	8.25%

Note: $\lambda_{max} = 5.041$; CI = 0.0102; CR = 0.0091

D1 is the most important dimension with a weight of 31.11%, followed by People: Commitment, Empowerment and Accountability (D2, 22.69%), Consistency for Food Safety (D4, 20.88%), Hazard and Risk Awareness (D3, 17.07%) and Adaptability, Change and Continuous Improvement (D5, 8.25%) (Table 7). The two foundation dimensions together account for 53.80% of the total weight, and D1, D2 and D4 together account for 74.68%. The gap between D2 and D4 is only 1.81 percentage points, so their relative order is the least stable part of the ranking, whereas the positions of D1 at the top and D5 at the bottom are clear. Because D1 and D2 both outweigh each of the three manifested dimensions, proposition P1 is supported.

3.3. Local and Global Weights of the Sub-Criteria (RQ2)

Table 7 reports the priority vector of each dimension and the local and global priority vectors of its sub-criteria, and Figure 2 ranks the 16 sub-criteria by global weight. Vision and values (D1.1) is the single most important element, with a local weight of 57.27% within D1 and a global weight of 17.82%. It is followed by FSMS implementation (D4.1, 11.57%), Accountability and ownership (D2.1, 10.70%), Risk awareness and perception (D3.1, 9.84%) and Leadership commitment (D1.2, 7.31%). These five sub-criteria together carry 57.24% of the total weight, so about a third of the elements accounts for more than half of the priority.

Within each dimension, one sub-criterion clearly dominates: D1.1 in D1 (57.27%), D2.1 in D2 (47.14%), D3.1 in D3 (57.65%), D4.1 in D4 (55.44%) and D5.2 Continuous improvement in D5 (49.90%). At the bottom of the global ranking are Behaviour and attitude (D2.4, 2.88%), Responsiveness to change (D5.1, 2.77%) and Learning from incidents and complaints (D5.3, 1.36%). Leadership commitment (D1.2, 7.31%) carries a higher global weight than Training and knowledge (D3.2, 4.16%), so proposition P2 is supported.

Table 7. Priority Vector and Global Priority Vector of Dimensions and Sub-Criteria

No.	Dimension / sub-criterion	Local weight (%)	Global weight (%)	Global rank
D1	Company Values, Vision and Mission	31.11	–	Dim. 1
D1.1	Vision & values	57.27	17.82	1
D1.2	Leadership commitment	23.49	7.31	5
D1.3	Communication of expectations	19.24	5.99	6
D2	People: Commitment, Empowerment and Accountability	22.69	–	Dim. 2
D2.1	Accountability & ownership	47.14	10.70	3
D2.2	Recognition & empowerment	18.59	4.22	10
D2.3	Teamwork & coordination	21.57	4.89	8
D2.4	Behaviour & attitude	12.70	2.88	14
D3	Hazard and Risk Awareness	17.07	–	Dim. 4
D3.1	Risk awareness & perception	57.65	9.84	4
D3.2	Training & knowledge	24.35	4.16	11
D3.3	Hazard reporting & speaking up	18.00	3.07	13
D4	Consistency for Food Safety	20.88	–	Dim. 3
D4.1	FSMS implementation	55.44	11.57	2
D4.2	Work pressure & resource adequacy	20.29	4.24	9
D4.3	Work environment & infrastructure	24.27	5.07	7
D5	Adaptability, Change and Continuous Improvement	8.25	–	Dim. 5
D5.1	Responsiveness to change	33.60	2.77	15
D5.2	Continuous improvement	49.90	4.12	12
D5.3	Learning from incidents & complaints	16.49	1.36	16

Note: global weight = dimension weight × local weight.

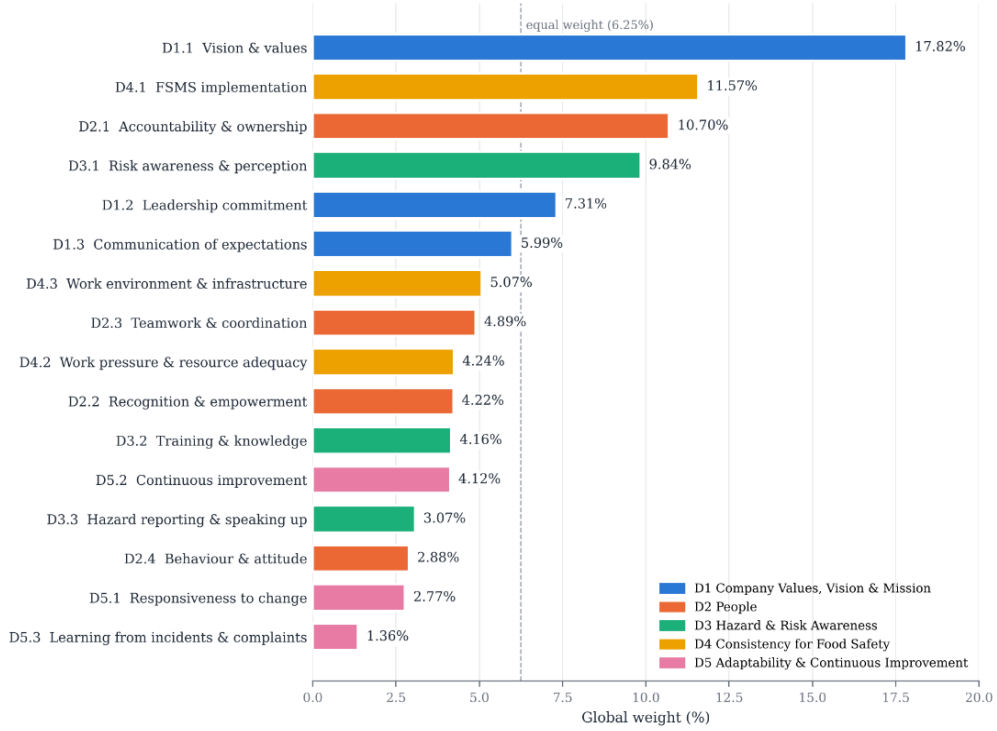


Figure 2. Global Weights of the 16 Food Safety Culture Sub-Criteria

3.4. Differences Across Expert Functions and Inter-Expert Agreement (RQ3)

The priorities differ between expert functions, as can be seen on Table 8. The QA/QC team and the consultants both rank D1 first, with weights of 35.13% and 37.99%, whereas the production team ranks D2 first (28.32%) and D1 second (24.21%). The QA/QC team gives D2 and D4 the same weight (19.44%), and the consultants rank D4 slightly above D2. All three functions rank D5 last, and they assign D3 a similar weight of 16.2% to 17.6%.

Table 8. Dimension Weights by Expert Function

Expert function	D1	D2	D3	D4	D5
QA/QC team (E1–E4)	35.13% (1)	19.44% (2)	16.15% (4)	19.44% (2)	9.83% (5)
Production team (E5–E8)	24.21% (2)	28.32% (1)	17.58% (4)	22.54% (3)	7.35% (5)
Consultants (E9–E10)	37.99% (1)	18.70% (3)	16.95% (4)	19.47% (2)	6.89% (5)
All experts (E1–E10)	31.11% (1)	22.69% (2)	17.07% (4)	20.88% (3)	8.25% (5)

At the individual level, D1 is the top dimension for six of the ten experts, D4 for two (Experts 3 and 7), D2 for one (Expert 5) and D3 for one (Expert 8), and D5 is ranked last by eight experts. Despite this variation, Kendall's W for the dimensions is 0.520 ($\chi^2 = 20.80$, df = 4, $p < 0.001$), which indicates moderate and statistically significant agreement [29]. Agreement within the five sub-criterion clusters is similar, with W between 0.490 and 0.536 and $p < 0.01$ for every cluster. Because priorities differ between functions while overall agreement is significant, proposition P3 is supported.

3.5. Discussion

This study does not simply replicate the AHP procedure; it uses it to turn a descriptive framework for food safety culture into a weighted set of priorities for a specific manufacturer. The results answer the three research questions and support all three propositions.

Values and people come first. The dominance of D1 and the strong position of D2 confirm empirically that the experts treat the two GFSI foundation dimensions as the base of food safety culture [13]. This pattern is consistent with evidence that leadership shapes commitment through communication, management systems and the work environment [20], and with the finding that transformational leadership is linked to stronger cultures [2]. It also mirrors earlier multicriteria studies in food safety, in which ineffective management and weak manager commitment emerged as the leading barriers to HACCP adoption and standards implementation [9], [26].

Systems still matter. FSMS implementation (D4.1) ranks second globally, which shows that the experts do not regard culture as a substitute for a documented and verified system. Certified companies can nevertheless show weak risk perception and optimistic bias among food handlers [19], so the high weight of D4.1 should be read as a call to make the system work through people rather than as a reason to rely on certification alone [1], [5].

Risk awareness is concentrated in one element. D3 ranks fourth as a dimension, and Risk awareness and perception (D3.1) also ranks fourth among all sub-criteria. This suggests that the experts value correct perception of hazards highly but see it as following from leadership and accountability rather than as a starting point. The low weight of Hazard reporting and speaking up (D3.3) deserves attention, because a culture in which errors are not reported cannot learn from them.

Adaptability is treated as a later stage. D5 ranks last for all three functions and for eight of the ten experts, which suggests that continuous improvement is seen as something to build once the foundation and consistency are in place. This sequencing is plausible, but the very low weight of Learning from incidents and complaints (D5.3) is a risk for a manufacturer whose product category is exposed to recurring causes of recalls, such as pathogens, allergens and labelling errors [5], [6], [14].

Functions see culture differently. The production team's preference for D2 over D1 is consistent with its direct responsibility for operators, shifts and daily behaviour, while QA/QC and consultants emphasize vision and management commitment. The moderate rather than strong agreement (W = 0.520) is therefore a substantive finding, because it shows where internal alignment is needed before an improvement programme is launched [29].

Theoretical and managerial implications. Theoretically, the study moves food safety culture research from describing and measuring dimensions towards weighting them, and it provides an expert-based AHP test of the foundation-first logic of the 2026 GFSI model [11], [13]. Practically, it gives PT XYZ a sequenced roadmap. Phase 1 should embed food safety explicitly in the company's vision and values, make leadership commitment visible and clarify accountability (D1.1, D1.2, D2.1). Phase 2 should strengthen FSMS implementation and risk perception on the shop floor (D4.1, D3.1), and Phase 3 should build structured learning from incidents and complaints (D5.2, D5.3).

3.6. Study Limitations

The following limitations should be considered when interpreting the results:

a. The panel of ten experts is small and the consultant group has only two members, so the comparison

between functions is indicative rather than statistically generalizable.

b. The study is a single case of one Indonesian food manufacturer, so the weights reflect its context and should be re-estimated before they are applied to other firms [8].

c. AHP assumes independence between elements at the same level, whereas food safety culture elements influence one another; interdependence-based methods such as ANP or DEMATEL could capture these links [9], [20].

d. Sub-criteria D3.3 and D5.3 were added to the instrument to complete their clusters and have thinner literature support than the other sub-criteria.

e. λ_{max} was approximated from geometric-mean weights rather than the exact principal eigenvector, and no sensitivity analysis of the dimension weights was performed.

4. Conclusion

This study prioritized the dimensions of food safety culture for PT XYZ, an Indonesian food manufacturer, by applying AHP to the judgements of ten QA/QC, production and consultant experts. Company Values, Vision and Mission are the most important dimension at 31.11%, followed by People at 22.69%, Consistency for Food Safety at 20.88%, Hazard and Risk Awareness at 17.07% and Adaptability, Change and Continuous Improvement at 8.25% (RQ1). At the sub-criterion level, Vision and values (17.82%), FSMS implementation (11.57%), Accountability and ownership (10.70%), Risk awareness and perception (9.84%) and Leadership commitment (7.31%) together carry 57.24% of the total weight (RQ2). Priorities differ between functions, as the production team ranks People first, but agreement across the panel is moderate and statistically significant ($W = 0.520$, $p < 0.001$) (RQ3). All judgement matrices are consistent ($CR \leq 0.10$), and all three propositions are supported. The contributions extend beyond PT XYZ. The study offers food manufacturers a transparent and replicable way to translate the Global Food Safety Initiative framework into weighted improvement priorities, and it gives researchers empirical support for the foundation-first structure of the food safety culture GFSI model. For the company, four actions are recommended. First, state food safety explicitly in PT XYZ's vision, values and strategic objectives, and make leadership commitment visible through resources, site presence and role modelling (D1.1, D1.2). Second, define food safety roles and responsibilities for every function and shift, and recognize employees who stop work or report problems (D2.1, D2.2, D3.3). Third, strengthen the verified implementation of the FSMS and target risk perception among operators, because certification alone does not guarantee a mature culture (D4.1, D3.1). Fourth, align the QA/QC and production teams on shared priorities before launching the improvement programme, and build structured learning from incidents and complaints into its later phases (D5.2, D5.3).

References

[1] Sharman, N., Wallace, C. A., & Jespersen, L. (2020). Terminology and the understanding of culture, climate, and behavioural change – Impact of organisational and human factors on food safety management. *Trends in Food Science & Technology, 96*, 13–20. https://doi.org/10.1016/j.tifs.2019.12.005

[2] Pai, A. S., Jaiswal, S., & Jaiswal, A. K. (2024). A comprehensive review of food safety culture in the food industry: Leadership, organizational commitment, and multicultural dynamics. *Foods, 13*(24). https://doi.org/10.3390/foods13244078

[3] Havelaar, A. H., Kirk, M. D., Torgerson, P. R., Gibb, H. J., Hald, T., Lake, R. J., Praet, N., Bellinger, D. C., de Silva, N. R., Gargouri, N., Speybroeck, N., Cawthorne, A., Mathers, C., Stein, C., Angulo, F. J., & Devleesschauwer, B. (2015). World Health Organization global estimates and regional comparisons of the burden of foodborne disease in 2010. *PLOS Medicine, 12*(12). https://doi.org/10.1371/journal.pmed.1001923

[4] Jaffee, S., Henson, S., Unnevehr, L., Grace, D., & Cassou, E. (2019). *The safe food imperative: Accelerating progress in low- and middle-income countries*. World Bank. https://doi.org/10.1596/978-1-4648-1345-0

[5] DeBeer, J., Blickem, E. R., Rana, Y. S., Baumgartel, D. M., & Bell, J. W. (2024). An analysis of food recalls in the United States, 2002–2023. *Journal of Food Protection, 87*(12). https://doi.org/10.1016/j.jfp.2024.100378

[6] Soon, J. M., & Abdul Wahab, I. R. (2021). Global food recalls and alerts associated with labelling errors and its contributory factors. *Trends in Food Science & Technology, 118*, 791–798. https://doi.org/10.1016/j.tifs.2021.11.001

[7] Surendra, H., Sujagat, A., & Wangge, G. (2026). Mitigating food safety risks in Indonesia's free school meals programme. *The Lancet Regional Health – Southeast Asia, 46*. https://doi.org/10.1016/j.lansea.2026.100734

[8] Nyarugwe, S. P., Linnemann, A. R., Ren, Y., Bakker, E.-J., Kussaga, J. B., Watson, D., Fogliano, V., & Luning, P. A. (2020). An intercontinental analysis of food safety culture in view of food safety governance and national values. *Food Control, 111*. https://doi.org/10.1016/j.foodcont.2019.107075

[9] Dima, A., Radu, E., & Dobrin, C. (2024). Exploring key barriers of HACCP certification adoption in the meat industry: A decision-making trial and evaluation laboratory approach. *Foods, 13*(9), 1303. https://doi.org/10.3390/foods13091303

[10] Lues, R., Jonker, J., Visser, M., & Skweyiya, N. (2026). Turn-key protocols for food safety culture improvement: A narrative on theory and best practice. *Foods, 15*(14). https://doi.org/10.3390/foods15142540

[11] Zanin, L. M., Stedefeldt, E., & Luning, P. A. (2021). The evolvement of food safety culture assessment: A mixed-methods systematic review. *Trends in Food Science & Technology, 118*, 125–142. https://doi.org/10.1016/j.tifs.2021.08.013

[12] Nayak, R., & Jespersen, L. (2022). Development of a framework to capture the maturity of food safety regulatory and enforcement agencies: Insights from a Delphi study. *Food Control, 142*. https://doi.org/10.1016/j.foodcont.2022.109220

[13] Global Food Safety Initiative. (2026). *A culture of food safety: A position paper from the Global Food Safety Initiative* (Version 2.0). The Consumer Goods Forum. Retrieved from https://mygfsi.com/publications/a-culture-of-food-safety-position-paper-from-the-global-food-safety-initiative/

[14] Liu, S., Roopesh, M. S., Tang, J., Wu, Q., & Qin, W. (2022). Recent development in low-moisture foods: Microbial safety and thermal process. *Food Research International, 155*. https://doi.org/10.1016/j.foodres.2022.111072

[15] Spagnoli, P., Defalchidu, L., Vlerick, P., & Jacxsens, L. (2024). The relationship between food safety culture maturity and cost of quality: An empirical pilot study in the food industry. *Foods, 13*(4). https://doi.org/10.3390/foods13040571

[16] Marconi, F., Sartoni, M., Nuvoloni, R., Torracca, B., Gagliardi, M., Zappalà, G., Guidi, A., & Pedonese, F. (2023). Food safety culture in food companies: Evaluation of the perception of food safety culture in three Tuscan food companies. *Italian Journal of Food Safety, 12*(1). https://doi.org/10.4081/ijfs.2023.11012

[17] Madzík, P., & Falát, L. (2022). State-of-the-art on analytic hierarchy process in the last 40 years: Literature review based on Latent Dirichlet Allocation topic modelling. *PLOS ONE, 17*(5). https://doi.org/10.1371/journal.pone.0268777

[18] Marzocca, P., Cerabona, V., Marcotrigiano, V., Farina, U., Tarricone, T., Tatoli, Y., Lampedecchia, M., Stingi, G. D., Spinelli, C., Forte, M. G., Rizzi, R., Dalena, A., Cinquetti, S., Normanno, G., Montagna, M. T., Napoli, C., De Giglio, O., & Caggiano, G. (2025). Food safety culture and education: A cross-sectional study in Southern Italy. *Foods, 14*(23). https://doi.org/10.3390/foods14234095

[19] Forte, G., Tornielli, S., Parini, D., & Lavelli, V. (2024). Certified food safety management systems assessed through the lenses of food safety culture and locus of control: A pilot study. *Foods, 13*(17). https://doi.org/10.3390/foods13172759

[20] da Cunha, D. T., Prates, C. B., Canuto, I. G., Stedefeldt, E., Luning, P. A., & Zanin, L. M. (2025). The relationship of food safety culture elements: A serial mediation model. *Food Control, 169*. https://doi.org/10.1016/j.foodcont.2024.111022

[21] Insfran-Rivarola, A., Tlapa, D., Limon-Romero, J., Baez-Lopez, Y., Miranda-Ackerman, M., Arredondo-Soto, K., & Ontiveros, S. (2020). A systematic review and meta-analysis of the effects of food safety and hygiene training on food handlers. *Foods, 9*(9). https://doi.org/10.3390/foods9091169

[22] D'Adamo, I. (2023). The analytic hierarchy process as an innovative way to enable stakeholder engagement for sustainability reporting in the food industry. *Environment, Development and Sustainability, 25*(12), 15025–15042. https://doi.org/10.1007/s10668-022-02700-0

[23] Saaty, T. L. (1990). How to make a decision: The analytic hierarchy process. *European Journal of Operational Research, 48*(1), 9–26. https://doi.org/10.1016/0377-2217(90)90057-I

[24] Lin, C., Kou, G., Peng, Y., & Hefni, M. A. (2022). Dynamic thresholds of geometric consistency index associated with pairwise comparison matrix. *Technological and Economic Development of Economy, 28*(4), 1137–1157. https://doi.org/10.3846/tede.2022.16544

[25] Aguarón, J., Escobar, M. T., Moreno-Jiménez, J. M., & Turón, A. (2022). Geometric compatibility indexes in a local AHP-group decision making context: A framework for reducing incompatibility. *Mathematics, 10*(2). https://doi.org/10.3390/math10020278

[26] Yadav, D., Dutta, G., & Kumar, S. (2024). Prioritizing strategies for overcoming barriers to food safety standards implementation using fuzzy AHP-TOPSIS approach. *Quality & Quantity, 58*(2), 1641–1663. https://doi.org/10.1007/s11135-023-01713-9

[27] Forman, E., & Peniwati, K. (1998). Aggregating individual judgments and priorities with the analytic hierarchy process. *European Journal of Operational Research, 108*(1), 165–169. https://doi.org/10.1016/S0377-2217(97)00244-0

[28] Kendall, M. G., & Babington Smith, B. (1939). The problem of *m* rankings. *The Annals of Mathematical Statistics, 10*(3), 275–287. https://doi.org/10.1214/aoms/1177732186

[29] Schmidt, R. C. (1997). Managing Delphi surveys using nonparametric statistical techniques. *Decision Sciences, 28*(3), 763–774. https://doi.org/10.1111/j.1540-5915.1997.tb01330.x