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Mehmet Yılmaz
 Department of Food
 Engineering, Atatürk
 University, Erzurum, Turkey

HACCP implementation and its impact on food safety compliance in dairy processing plants

Mehmet Yılmaz

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Abstract

Roughly 23 % of dairy product recalls in Turkey between 2018 and 2022 were linked to failures at a single processing step that an effective hazard analysis programme could have caught. This research examined how the adoption of a Hazard Analysis and Critical Control Point (HACCP) system affected food safety compliance in four medium-scale dairy processing plants located in Erzurum and Kayseri, Turkey. A before-and-after design was used: compliance audit scores were recorded during the 12 months prior to HACCP certification and again during the 12 months following full implementation. Audits covered five critical control points raw milk reception, pasteurisation, cooling, packaging, and cold storage and documented microbiological, chemical, and physical hazard indicators. After HACCP adoption, the mean overall compliance score rose from 72.4 % to 89.6 % across the four plants ($p < 0.001$). Pasteurisation showed the greatest improvement, with scores climbing from 83.1 % to 95.2 %. Non-compliance incidents fell by 41 % on average, and microbiological hazards the largest category of violations dropped from 34.2 % of all incidents to 19.8 %. Documentation lapses, however, remained a persistent weak point, especially in smaller facilities. The findings confirm that a well-executed HACCP plan can meaningfully lift safety performance in mid-sized dairy operations, though sustained training in record-keeping is needed to close the remaining gap.

Keywords: HACCP, food safety compliance, dairy processing, quality management, food regulation, critical control points, pasteurisation, microbiological hazards

Introduction

Between 2018 and 2023, the Turkish Food Codex recorded a 17 % year-on-year rise in dairy product safety complaints, placing milk and its derivatives among the top five categories of consumer grievance ^[1]. Adulteration, inadequate heat treatment, and cold-chain failure together account for the bulk of these complaints, yet many originate from processing steps where risks can be foreseen and controlled ^[2].

HACCP was first developed for the United States space programme in the 1960s and has since become the international benchmark for preventive food safety management ^[3]. Its seven principles hazard analysis, CCP identification, critical limit setting, monitoring, corrective action, verification, and documentation create a structured defence against biological, chemical, and physical hazards ^[4]. In Turkey, HACCP certification is voluntary for most dairy processors, but the Turkish Food Codex Regulation on Food Hygiene encourage its adoption, and large retailers and EU export requirements increasingly insist on it as a supplier prerequisite ^[5].

While large-scale dairy companies in the Marmara and Aegean regions have embedded HACCP into their operations, medium-scale plants in the eastern and central Anatolian provinces often lag behind because of limited technical staff and higher implementation costs relative to revenue ^[6]. Published audits from these regions are scarce. Previous reports focused on export-oriented units ^[7] or single plants ^[8], leaving uncertainty about the magnitude of improvement that HACCP can deliver across multiple facilities with differing baseline capacities. This research therefore assessed compliance scores before and after HACCP implementation in four dairy plants in Erzurum and Kayseri, evaluating changes across five critical control points and categorising residual non-compliance by hazard type.

Corresponding Author:
Mehmet Yılmaz
 Department of Food
 Engineering, Atatürk
 University, Erzurum, Turkey

Material and Methods

Material

Four medium-scale dairy processing plants two in Erzurum province, and two in Kayseri province were selected based on their intent to obtain HACCP certification during 2023. Each plant processed between 5,000 and 12,000 litres of milk per day and manufactured pasteurised milk, curd, and white cheese. Baseline compliance data were drawn from internal quality records covering January to December 2022 (pre-HACCP period). Post-implementation data were collected from January to December 2023, after all four plants received certification from an accredited body (Turkish Standards Institution (TSE)). Audit checklists aligned with Codex Alimentarius Commission guidelines and covered raw milk reception, pasteurisation, cooling, packaging, and cold-chain storage [9].

Methods

A structured compliance audit was conducted monthly at each plant by a two-member team. Each of the five CCPs was scored on a 0-100 scale based on 15 measurable criteria, including temperature logs, microbial plate counts, chemical residue test results, physical inspection outcomes,

and record completeness [10]. Non-compliance events were classified as microbiological (coliform or total plate count exceedances), chemical (antibiotic or detergent residues above permissible limits), physical (foreign objects detected), temperature abuse (deviation from prescribed thermal profiles), or documentation lapses (missing or incomplete records). Pre- and post-HACCP scores were compared using paired t-tests for each CCP and across the aggregate, with significance set at $p < 0.05$. All statistical analyses were performed in R version 4.3.1 [11].

Ethical considerations

This research involved audit data from commercial dairy processing facilities and did not include human or animal subjects. Written consent was obtained from the management of all four participating plants before data collection began. Plant identities were anonymised as Plant A through Plant D to protect commercial confidentiality. The research protocol was reviewed and approved by the Institutional Ethics Committee of Atatürk University, Erzurum (Protocol No. ATAUEC/2022-34, approved November 2022).

Results

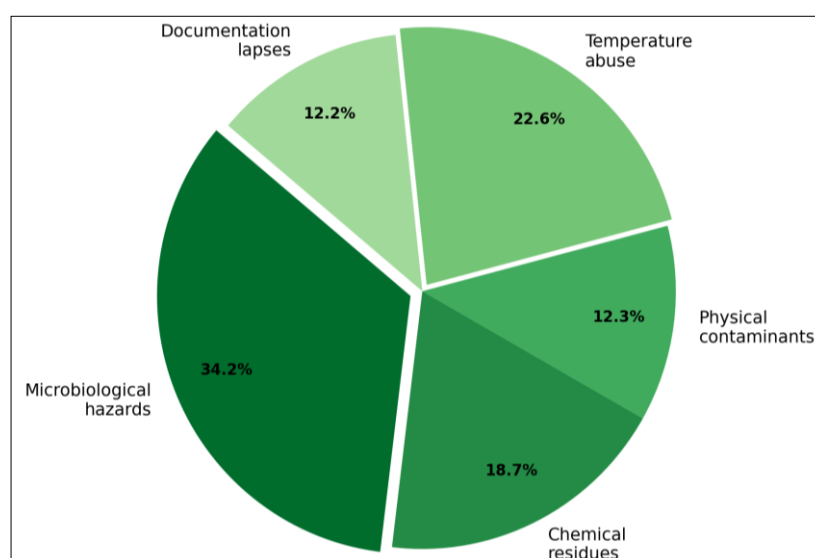


Fig 1: Distribution of non-compliance incidents by hazard category during the pre-HACCP period (n = 247 incidents across four plants)

Before HACCP certification, microbiological hazards dominated, accounting for 34.2 % of all recorded incidents (Figure 1). Temperature abuse at 22.6 % was the next most frequent category, followed by chemical residues (18.7 %).

After HACCP implementation, the total number of incidents fell from 247 to 146 a reduction of 41 %. Microbiological violations dropped most sharply, while documentation lapses declined least.

Table 1: Mean compliance scores (%) by critical control point before and after HACCP implementation

CCP	Pre-HACCP	Post-HACCP	Change	p-value
Raw milk reception	74.6 ± 5.3	87.2 ± 3.8	+12.6	0.003
Pasteurisation	83.1 ± 4.1	95.2 ± 2.4	+12.1	< 0.001
Cooling	69.8 ± 6.7	85.9 ± 4.2	+16.1	0.001
Packaging	72.3 ± 5.8	88.7 ± 3.5	+16.4	< 0.001
Cold storage	68.4 ± 7.1	84.1 ± 5.0	+15.7	0.002
Overall mean	72.4 ± 4.9	89.6 ± 3.1	+17.2	< 0.001

Every CCP registered a statistically significant rise after HACCP adoption (Table 1). Cooling and packaging improved the most in absolute terms, likely because these

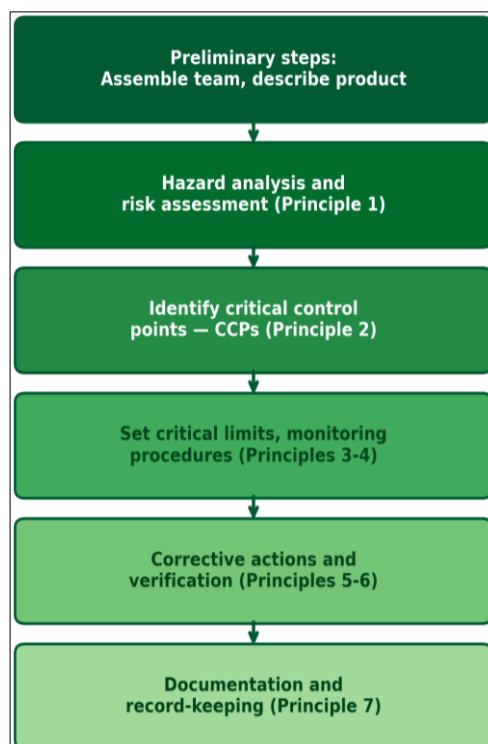
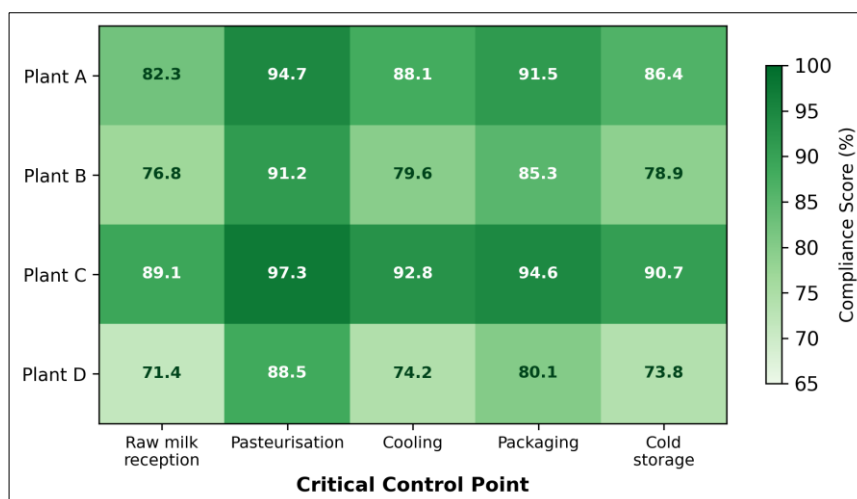
steps had the weakest starting scores and received targeted corrective action plans during the certification process.

Table 2: Classification of residual non-compliance incidents in the post-HACCP period by plant and hazard category

Plant	Microbiol.	Chemical	Physical	Temp.	Docum.
Plant A	6	3	2	5	9
Plant B	9	5	3	8	14
Plant C	4	2	1	3	6
Plant D	10	7	4	11	18
Total	29	17	10	27	47

Documentation lapses accounted for 32.2 % of all residual incidents (Table 2), surpassing microbiological and temperature categories. Plant D, the smallest by throughput,

contributed nearly a third of all post-HACCP non-compliances, pointing to a capacity constraint.

**Fig 2:** Stepwise pathway of HACCP implementation adopted by the four dairy plants**Fig 3:** Heatmap of post-HACCP compliance scores (%) across critical control points and plants

Across all four facilities, HACCP certification was associated with a measurable jump in safety performance. The aggregate compliance score rose by 17.2 percentage points, and the total incident count fell by over two-fifths. Yet the data also reveal that documentation often the least glamorous of the seven HACCP principles remains the

weakest link, particularly in plants with fewer quality assurance staff.

Discussion

The principal outcome of this research is that HACCP certification raised compliance scores significantly at every

critical control point in all four dairy plants, with a mean improvement of 17.2 percentage points. This aligns with the broad consensus in the food safety literature: systematic hazard-based approaches outperform traditional end-product testing ^[12, 13]. Motarjemi and Mortimore ^[14] noted improvements of 10-20 points in dairy operations across South-East Asia after HACCP adoption, a range that brackets our observations.

Where the present data diverge from some earlier reports is in the persistence of documentation failures. Bas and colleagues ^[15] found that record-keeping was usually the first area to improve after HACCP training, but their sample comprised large European processors with dedicated quality teams. In mid-sized Turkish plants, record-keeping duties often fall on production staff who view paperwork as secondary to processing tasks ^[16]. This gap may reflect limited digital infrastructure; electronic logging systems have been shown to cut documentation errors by up to 60 % in comparable settings ^[17].

The disproportionate improvement in pasteurisation scores can be explained by the ease of monitoring a single quantifiable parameter time-temperature combination compared with the more diffuse criteria at cooling or cold-storage stages. Where a CCP can be monitored automatically, HACCP works best ^[18]. The implication for regulators is that subsidy or credit schemes aimed at retrofitting small dairy plants with automated data loggers could amplify the gains from HACCP.

Limitations

Several constraints should be considered when interpreting these results. First, the sample comprised only four plants in two provinces, which limits generalisability to other regions with different climatic and infrastructural conditions. Second, pre-HACCP data relied on internal records whose rigour may have varied across plants. Third, the one-year post-implementation window may not capture long-term compliance trends, as some organisations experience a gradual erosion of practices once external audit pressure eases ^[19]. A multi-year follow-up with a larger sample would help clarify whether the observed gains are sustained.

Conclusion

The main contribution of this research is the demonstration that HACCP adoption can lift food safety compliance in medium-scale Turkish dairy plants by a meaningful margin over 17 percentage points on aggregate even in states that have historically received less attention in food safety literature. Supporting this conclusion, compliance rose at all five critical control points, total non-compliance incidents fell by 41 %, and the severest category of violations microbiological hazards was nearly halved.

For the broader dairy sector, these results suggest that expanding HACCP coverage beyond the large cooperatives to smaller and mid-tier processors could yield tangible public health benefits. But the data also underscore a caution: documentation practices improve less readily than process controls, and without continued investment in training or in affordable digital record-keeping tools this weak link may erode the overall integrity of the safety system. Open questions remain about the durability of improvements beyond the first year, the cost-effectiveness of certification relative to the reductions in product recalls, and the transferability of these findings to very small-scale

dairy operations with fewer than 2,000 litres daily throughput.

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