

INTRODUCTION

The food and health industries increasingly rely on natural mineral agents for processing efficiency and safety assurance (Shirvani et al., 2023). Natural fining agents—specifically bentonite, sepiolite, and gelatin—are highly effective in fruit juice clarification and mycotoxin decontamination (Hamad et al., 2023; Jafari et al., 2024). While their therapeutic and industrial benefits are evident, the natural geological formation of these clays can introduce hazardous elements and heavy metals, raising severe public health concerns regarding their direct consumption (Demaegdt et al., 2021; Özmen, 2016). This study reviews the efficacy of natural fining agents in food processing while critically evaluating their safety profile for human health in the context of geogenic risks.

OBJECTIVE

The primary objective of this research is to evaluate the efficacy of natural fining agents (bentonite, sepiolite, and gelatin) in fruit juice clarification and mycotoxin (Aflatoxin M1) decontamination. Furthermore, it aims to establish food safety boundaries by investigating potential geogenic and chemical risks, such as sodium leaching, bioaccessible arsenic toxicity, and heavy metal/silica anomalies found in traditional edible clays, to ensure consumer safety.

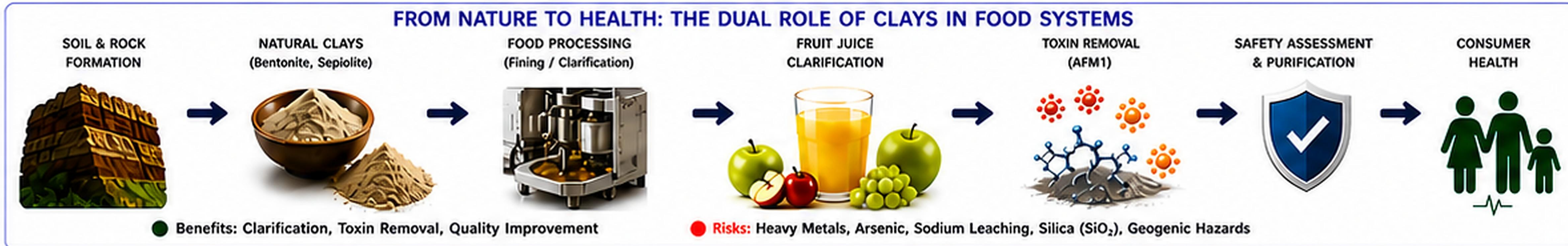
METHODOLOGY

This study employed a mixed "comprehensive review and empirical case synthesis" approach to investigate the risk-benefit relationship between industrial applications and traditional uses of clays. Data regarding juice clarification and Aflatoxin M1 (AFM1) adsorption capacity were collected through a comprehensive literature review (Jafari et al., 2024; Mirzaaghaei et al., 2018; Hamad et al., 2023). The toxicological and geogenic safety of clays used in traditional food processing (e.g., molasses clarification) was evaluated through an empirical case study. In this context, **33 traditional clay samples ("pekmez toprağı") were collected from 18 different locations in the Denizli region of Turkey, and their mineralogical and chemical compositions were analyzed using X-ray Diffraction (XRD), X-ray Fluorescence (XRF), Fourier Transform Infrared Spectroscopy (FTIR), and Scanning Electron Microscopy (SEM) techniques (Özmen, 2016).**



CONCLUSION

Natural clays and fining agents offer highly efficient performance in fruit juice clarification and mycotoxin detoxification. However, as clearly demonstrated by empirical findings and safety assessments (Özmen, 2016), the application of clays cannot be considered independent of toxicological screening. To guarantee consumer safety, elemental leaching (e.g., sodium) must be monitored during industrial food processing, and both commercial dietary clays and raw materials used in traditional food preparation (e.g., molasses) must be strictly regulated and purified for heavy metal and silica content.



RESULTS

- In industrial fruit juice processing, a combination of 1.5 mg/mL gelatin and 1 mg/mL bentonite completely inhibited microbial growth in Indian gooseberry juice (Jafari et al., 2024), while acid-activated sepiolite-based combinations achieved a 99.7% reduction in turbidity in apple juice (Mirzaaghaei et al., 2018).
- However, sodium-activated bentonites used in apple juice resulted in up to 8.4 mg/L sodium release into the final product (Valdhuber & Pulko, 2022).
- In milk, specific bentonite variants (HAFR 3) demonstrated up to 98.5% adsorption efficiency for Aflatoxin M1 (Hamad et al., 2023).
- Regarding safety parameters, dietary clay supplements were found to contain bioaccessible inorganic arsenic ranging from 8% to 51% (Demaegdt et al., 2021).
- Furthermore, empirical XRD and XRF analyses conducted within the case study revealed critical silica (SiO₂) anomalies up to 44.31%, along with heavy metal anomalies such as titanium (TiO₂, up to 0.63%) and chromium (Cr₂O₃, up to 0.04%) in traditional clays used directly in food (molasses) clarification (Özmen, 2016).

ANALYSIS

The results highlight a "Medical Geology Paradox" in the use of natural clays and fining agents. While the electrostatic properties of bentonite and sepiolite make them superior agents for eliminating turbidity-causing structures and carcinogenic AFM1 (Hamad et al., 2023; Shirvani et al., 2023), they pose significant risks when used raw or unpurified. The arsenic levels in commercial ingestible clay products (Demaegdt et al., 2021) and the empirically proven extreme silica and chromium/titanium levels (Özmen, 2016) demonstrate that high adsorption capacity is a double-edged sword. Clays can successfully sequester toxins in food, but without mineralogical purification, they directly expose humans to geogenic risks such as cellular mutation, heavy metal toxicity, and silicosis.

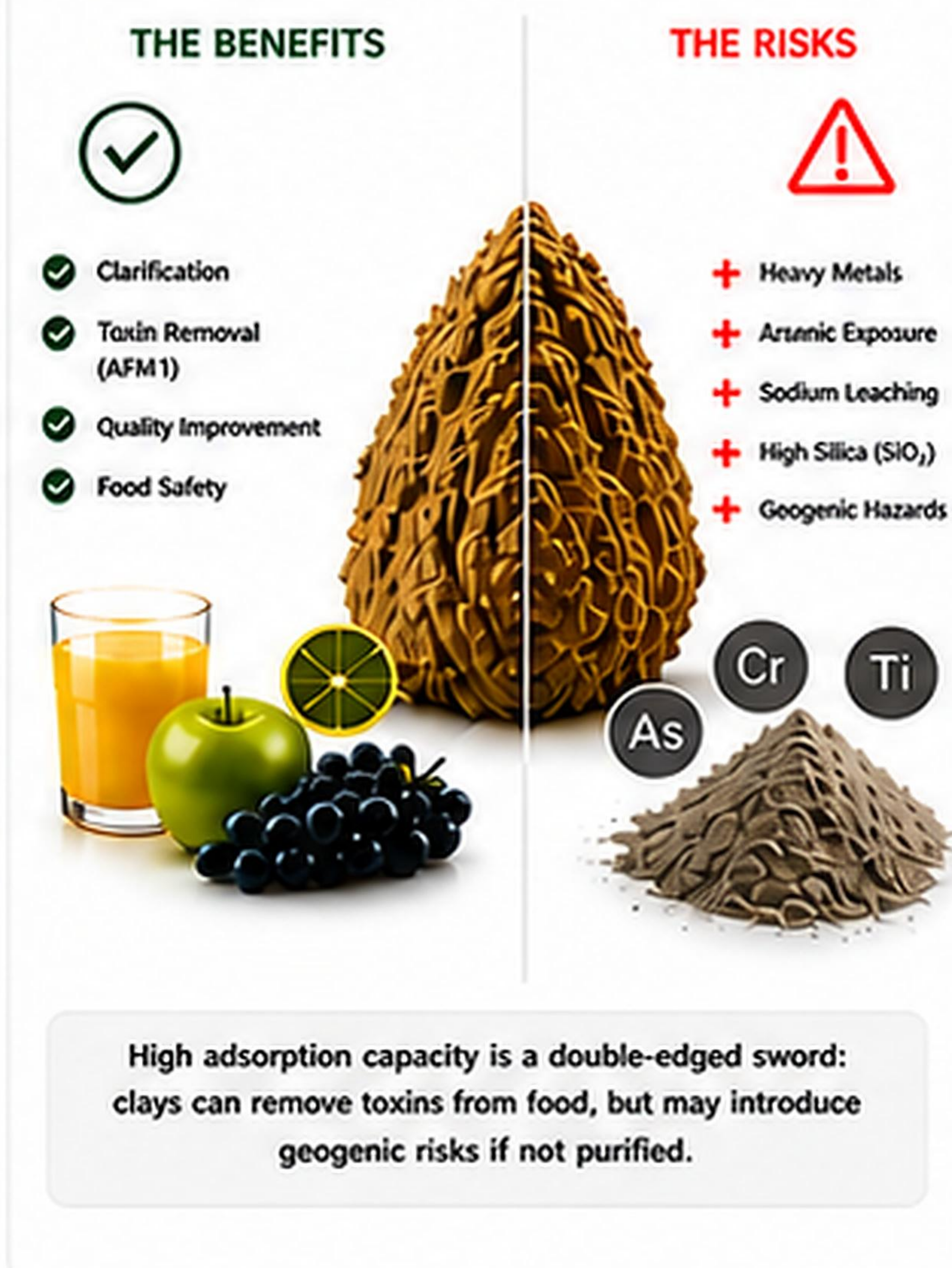
MEDICAL GEOLOGY PARADOX

THE BENEFITS

- ✓ Clarification
- ✓ Toxin Removal (AFM1)
- ✓ Quality Improvement
- ✓ Food Safety

THE RISKS

- + Heavy Metals
- + Arsenic Exposure
- + Sodium Leaching
- + High Silica (SiO₂)
- + Geogenic Hazards



High adsorption capacity is a double-edged sword: clays can remove toxins from food, but may introduce geogenic risks if not purified.

Table 1: Efficacy of Natural Clays and Fining Agents in Industrial Food Processing

Application Area	Fining Agent / Treatment	Key Findings & Adsorption Efficacy	References
Indian Gooseberry Juice	1.5 mg/mL gelatin + 1 mg/mL bentonite	Significantly improved transmittance and antioxidant activity; completely inhibited microbial growth during 49 days of storage.	(Jafari et al., 2024)
Apple Juice Clarification	Acid-activated sepiolite + gelatin + silica gel	Outperformed single-agent treatments, achieving a dramatic 99.7% reduction in turbidity.	(Mirzaaghaei et al., 2018)
Raw Milk Detoxification	Bentonite variant (HAFR 3)	Demonstrated an adsorption efficiency of up to 98.5% for Aflatoxin M1 (AFM1), a potent carcinogen, in milk within 12 hours.	(Hamad et al., 2023)

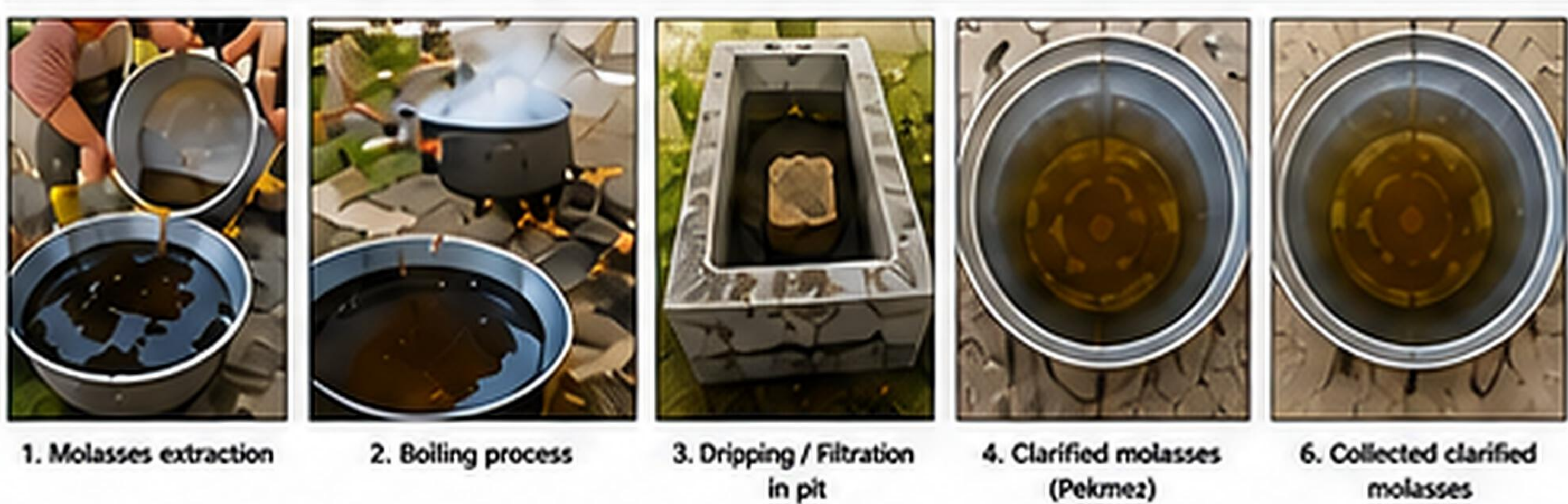
Table 2: Industrial and Toxicological Safety Assessments of Clay Application

Application / Product	Risk Factor	Key Findings & Observations	References
Apple Juice Fining	Sodium leaching	Sodium-activated bentonites showed a direct correlation between sodium in the activator and increased sodium release (up to 6.6 mg/L) into the final juice.	(Valdhuber & Pulko, 2022)
Milk Decontamination	Nutritional alterations	The non-selective high adsorption capacity of bentonite caused minor alterations to milk's nutritional composition (increased fat/protein, decreased lactose).	(Hamad et al., 2023)
Edible Clays (Supplements)	Inorganic arsenic exposure	Directly consumed clay dietary supplements were found to contain bioaccessible inorganic arsenic ranging from 8% to 51%, posing chronic health risks.	(Demaegdt et al., 2021)

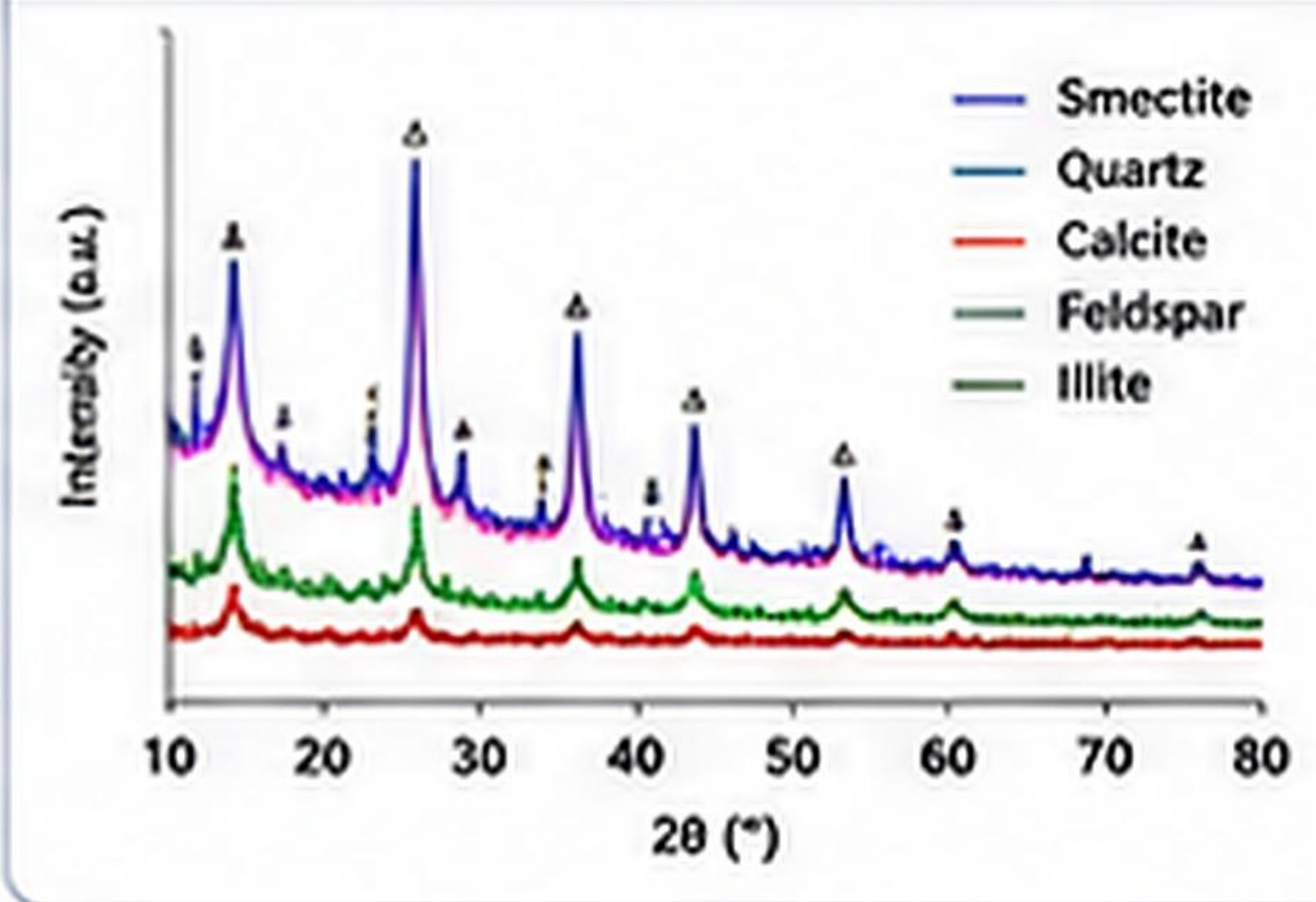
Table 3: Geogenic Risk Assessment in Traditional Food Processing (Case Study: Turkey)

Application Area	Evaluated Geogenic Risk	Empirical Findings & Safety Concerns	References
Traditional Grape Molasses (Pekmez) Clarification	Extreme Silica (SiO ₂) Anomalies	Laboratory XRD/XRF analyses of clays used in traditional food revealed dangerous SiO ₂ levels reaching up to 44.31%, carrying long-term risks of chronic silicosis and tissue damage.	(Özmen, 2016)
Traditional Grape Molasses (Pekmez) Clarification	Trace Heavy Metal Contamination	Raw "pekmez toprağı" used directly in must clarification showed significant trace element anomalies, including Chromium (Cr ₂ O ₃ = 0.04%) and Titanium (TiO ₂ = 0.63%), proving the necessity for purification.	(Özmen, 2016)

EMPIRICAL EVIDENCE FROM CASE STUDY (Traditional Clay Use in Molasses, Denizli Region)



XRD ANALYSIS (Sample: Traditional Clay)



KEY REFERENCES

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