ISSN: 2634 - 8853

Journal of Engineering and Applied Sciences Technology

SCIENTIFIC Research and Community

Research Article

Open Access

Integrated Process Optimization and Defect Analysis to Minimize Glass Jar Breakage in Acidified Gherkin Packaging Lines

Mohan KR* and Ravichandra

Department of Food Science and Technology, Mahatma Gandhi Rural Development and Panchayat Raj University, Gadag, 582103, Karnataka, India

ABSTRACT

Glass packaging plays a pivotal role in maintaining the safety, integrity, and market quality of acidified gherkin products. However, frequent glass jar breakage during processing and handling presents a critical operational and sustainability challenge in pickle manufacturing lines. This study was conducted at Global Green Company Limited, Bangalore, to identify, analyze, and minimize glass jar breakage through an integrated process-optimization framework. Breakage data were collected across two production lines and four critical points—pasteurizer outfeed, dud detector, downing area, and conveyor system. Quantitative evaluation revealed higher defect incidence in large-capacity jars (1400–2000 ml), with thermal shock and mechanical vibration being the most significant contributors. Implementation of corrective measures, including gradual cooling, conveyor synchronization, torque calibration, and operator retraining, resulted in an average 51.7% reduction in breakage, confirmed statistically ($t = 3.49$, $p < 0.05$, Cohen's $d = 1.56$). Post-intervention, the mean defect rate declined from 7.3% to 3.52%, improving line efficiency and reducing waste generation by 35%. The findings establish that systematic process optimization combining root cause analysis and engineering controls can effectively enhance packaging integrity, economic performance, and sustainability in glass-packaged food manufacturing.

***Corresponding author**
Mohan KR, Department of Food Science and Technology, Mahatma Gandhi Rural Development and Panchayat Raj University, Gadag, 582103, Karnataka, India.

Received: December 01, 2025; **Accepted:** December 08, 2025; **Published:** December 16, 2025

Keywords: Glass Packaging, Process Optimization, Defect Analysis, Root Cause Evaluation, Thermal Stress, Gherkin Pickle Processing, Sustainable Manufacturing

Introduction

Background and Importance of Glass Packaging

Glass packaging continues to hold a dominant position in the global food industry due to its chemical stability, inertness, recyclability, and superior barrier properties against oxygen and moisture [1,2]. In products such as acidified gherkin pickles, glass jars are preferred because they prevent acid–material interaction and provide an aesthetically transparent package that enhances consumer confidence and brand appeal [3]. Globally, glass containers constitute approximately 23% of packaged pickled products, with rising consumer preference for reusable packaging materials aligning with circular economy principles [4,5].

Despite its environmental and sensory advantages, glass packaging is mechanically brittle. Breakage during manufacturing or post-filling remains a significant issue, resulting in material loss, safety hazards, production delays, and additional energy consumption [6]. Glass failure is primarily influenced by thermal gradients, impact loads, and surface defects [7]. The high thermal conductivity of the jar content, combined with sudden temperature shifts during pasteurization or cooling, induces localized stresses that exceed the material's tensile strength [8]. When compounded by conveyor misalignment or mechanical shock at transfer points, breakage rates can rise substantially [9].

Industry Context and the Gherkin Packaging Problem

India's gherkin industry plays a vital role in agricultural export, with over 250,000 tonnes of gherkin products processed annually. Major producers like Global Green Company Limited, Bangalore, depend heavily on high-throughput automated filling and pasteurization lines.

The packaging operations employ returnable glass jars of multiple capacities—370 ml, 720 ml, 1000 ml, 1400 ml, and 2000 ml. Field observations revealed that glass jar breakage occurs recurrently at four distinct process locations:

- **B1 – Pasteurizer Outfeed:** Rapid cooling after heat treatment causes thermal shock.
- **B2 – Dud Detector:** Impact during inspection and rejection leads to rim fractures.
- **B3 – Downing Area:** Manual handling contributes to neck and sidewall cracks.
- **B4 – Conveyor Transfer:** Vibration and mechanical misalignment induce base stress fractures.

Preliminary records indicated breakage rates of 8–12% for larger jars (1400–2000 ml) and 3–4% for smaller formats, leading to daily losses of over ₹40,000 and indirect production delays. The company sought a process-engineering-based solution to systematically identify the root causes and implement feasible corrective actions.

Theoretical and Scientific Framework

Glass breakage in food-packaging systems is a multifactorial problem influenced by mechanical design, process temperature, and operational handling. Finite element simulations show that glass jars experience peak tensile stress near the shoulder and base radius, particularly when subjected to differential cooling between the interior brine and exterior surface [7]. Sudden cooling after pasteurization (temperature drop >50°C within 1 minute) can produce internal thermal stress exceeding 35 MPa, surpassing the typical strength of soda-lime glass (27–30 MPa). Moreover, research by Gul et al. demonstrated that microscopic scratches from conveyor contact act as crack initiation sites, amplifying stress concentration by a factor of 3–5 during loading [1].

Recent advances in process optimization and quality control—such as Six Sigma (and Statistical Process Control—have proven effective in the glass and beverage industries, yielding 30–70% defect reduction [6,9].

However, these methodologies remain underutilized in the food-packaging sector, especially in acidic product lines where combined chemical, thermal, and mechanical stresses occur.

Literature Insights and Research Gap

While multiple studies have explored glass manufacturing defects, few have focused on post-production breakage during actual filling and cooling operations in food environments [10,11].

For instance, Schaut and Weeks examined parenteral vial failures due to thermal cycling and suggested that similar stress mechanisms could apply to food jars [12]. Likewise, Tucker and Featherstone highlighted that improper pasteurization gradients can compromise container durability, affecting product shelf life [13].

Despite these contributions, integrated defect-reduction frameworks combining empirical data collection, root cause analysis, and process re-engineering are scarcely reported for pickle manufacturing lines. This research bridges that gap by providing a comprehensive diagnostic and improvement model for defect reduction in industrial food packaging.

Objectives

The objectives of this study were to:

- Identify and categorize major glass breakage points within gherkin packaging lines.
- Quantify defect occurrence by jar size and process stage.
- Analyze root causes using structured tools such as Fishbone (Ishikawa) diagrams and Pareto analysis.
- Implement and validate corrective measures focusing on temperature management, equipment alignment, and human factors.
- Evaluate the overall impact on breakage rate reduction and process stability.

Significance and Contribution

The research integrates industrial data with analytical quality tools to produce actionable insights for packaging reliability.

The findings have threefold significance:

- **Scientific Contribution:** Demonstrates how stress mechanisms translate to breakage patterns under real production conditions, complementing theoretical models [7].
- **Practical Application:** Provides a data-driven framework for defect analysis applicable to similar packaging lines across the food sector.
- **Sustainability Impact:** Reduces material waste, improves equipment lifespan, and aligns with circular packaging initiatives [5].

This study thus contributes to the expanding field of packaging process optimization by aligning traditional glass packaging practices with modern quality management methodologies.

Review of Literature

Overview of Glass Packaging Performance

Glass containers remain the most trusted medium for acidic food packaging due to their inertness, impermeability, and aesthetic appeal [1]. However, the mechanical reliability of glass is inherently constrained by microstructural flaws, which act as fracture initiation sites under thermal and mechanical stress [12]. Recent studies emphasize that the residual stress generated during hot filling and cooling cycles contributes significantly to crack propagation and breakage [10,13].

According to Moursi and Allam, even minor inconsistencies in annealing can alter the stress profile of glass containers, leading to brittle failure under minimal impact [13]. Similarly, Yoon et al. demonstrated that surface defects smaller than 50 μm can reduce compressive strength by 40%, making the control of handling conditions crucial in high-speed filling lines [15].

Thermal Stress and Shock in Food Packaging Lines

Thermal stress is a leading factor influencing glass jar breakage in hot-filled or pasteurized food products. When a filled jar exits a pasteurizer, it experiences a rapid temperature gradient between its inner and outer surfaces.

Finite element modeling by Puri and Anantheswaran revealed that a temperature differential exceeding 60 °C/min causes internal tensile stress surpassing 30 MPa—the failure threshold for soda-lime glass [7]. More recently, Dambrosio et al. confirmed that uneven cooling after pasteurization leads to stress concentration around the jar shoulder and base, the two most fracture-prone zones [16].

In the food sector, improper cooling conditions, nonuniform brine temperature, and inadequate control of pasteurizer outfeed time exacerbate these effects. Legesse and Geremew reported that optimizing cooling ramp rates and aligning jar conveyors reduced breakage by nearly 45% in a condiment packaging plant [11].

Mechanical Stress and Conveyor Dynamics

Mechanical stress accounts for nearly half of all breakages reported in packaging plants [8]. Conveyor vibration, impact between jars, and torque misalignment during transfer cause micro-cracking, which eventually leads to base or shoulder fractures.

Recent vibration diagnostics by Hsu et al. introduced accelerometer-based condition monitoring systems capable of detecting stress amplitudes exceeding 10 g at transfer points, allowing predictive maintenance to reduce defects [17].

Similarly, Zhao and Li showed that synchronized conveyor motion, coupled with torque control in star-wheel transfers, can cut impact energy by 25–30%, improving jar survival during filling and inspection [18].

Human and Environmental Factors

In addition to equipment-induced stress, operator handling, humidity, and storage conditions influence glass stability. Improper stacking and high moisture exposure accelerate surface corrosion, weakening mechanical integrity [3]. Uthpala et al. highlighted that pre-fill jar storage under 75–85% relative humidity increased defect probability by 20% within 24 hours due to alkali leaching [19]. Training and ergonomic redesign of manual handling areas have shown measurable improvements in defect reduction [9].

Process Optimization and Quality Improvement Approaches

Modern food packaging industries increasingly employ Six Sigma (DMAIC), Lean Manufacturing, and Root Cause Analysis (RCA) frameworks to address breakage issues.

Dutta and Jaipuria reported a 68% reduction in packaging defects in beverage lines using Six Sigma integration with real-time SPC dashboards [6]. Likewise, Konopek et al. applied Pareto prioritization to eliminate recurring mold defects in a glass mill, achieving a 35% quality improvement [10].

For food packaging, integrating statistical methods with thermal and mechanical modeling allows early identification of high-risk conditions. Studies by Bhunia et al. and Moursi and Allam emphasize the need for a multidisciplinary approach combining materials science, mechanical design, and process analytics to ensure sustainable packaging performance [4,14].

Research Gap

Despite extensive literature on glass manufacturing defects, few studies analyze in-line glass breakage under actual food-processing conditions, particularly within acidified vegetable packaging systems.

The reviewed works identify stress mechanisms individually—thermal, mechanical, or handling—but seldom combine them into an integrated optimization framework. Moreover, existing studies are primarily based on laboratory testing rather than empirical industrial data.

Therefore, a comprehensive field-based investigation that correlates process parameters, jar geometry, and mechanical behavior is essential to formulate effective defect-reduction strategies.

The present research fills this gap by evaluating multiple critical points within a live gherkin pickle manufacturing line, applying data-driven root cause analysis, and implementing process-level interventions to minimize glass breakage.

Materials and Methods

Study Site and Operational Context

This study was conducted at Global Green Company Limited, Bangalore, India, a major processor and exporter of acidified gherkin pickles. The facility operates two semi-automated glass packaging lines that process approximately 24,000 jars per day across five jar capacities—370 ml, 720 ml, 1000 ml, 1400 ml, and 2000 ml. Each line comprises sequential units for jar washing, hot brine filling, pasteurization, cooling, capping, inspection, and labeling.

Glass breakage was observed during multiple stages, prompting a systematic investigation to isolate mechanical and thermal factors contributing to product loss. The production environment follows ISO 22000:2018 food safety standards and Good Manufacturing Practices (GMP) for quality control.

Experimental Design and Observation Framework

Study Duration and Sampling Frequency

Data were collected over 30 consecutive production days. Each day was treated as one observational unit, with defect data captured from both packaging lines.

Identification of Critical Breakage Points

Preliminary inspection and operator interviews identified four major critical points (B1–B4):

Code	Process Stage	Description of Operation
B1	Pasteurizer Outfeed	Transition from heated brine to ambient temperature; high thermal gradient exposure
B2	Dud Detector	High-speed mechanical rejection mechanism; impact-induced rim fractures
B3	Downing Area	Manual jar handling post-inspection; potential for neck and shoulder cracks
B4	Conveyor Section	Continuous motion and vibration during transfer; base stress failures

Data Collection and Measurement Parameters

Breakage Monitoring

All jars were counted using photoelectric PLC-based counters at the start and end of each batch. Defective jars were visually inspected, classified by failure mode (rim chip, base crack, shoulder fracture, or total shatter), and recorded in a standardized quality log.

Instrumentation

Parameter	Instrument Used	Accuracy
Temperature (pasteurizer zones)	Type-K digital thermocouples	±0.1 °C
Conveyor vibration	Portable accelerometer	±0.05 g
Conveyor speed	Optical tachometer	±1 rpm
Ambient humidity	Digital hygrometer	±1 % RH

Temperature readings were logged continuously at the pasteurizer inlet and outlet, capturing the cooling rate across the thermal transition. Vibration and torque were measured at the start and end of each conveyor line.

Analytical Methods

Quantitative Analysis

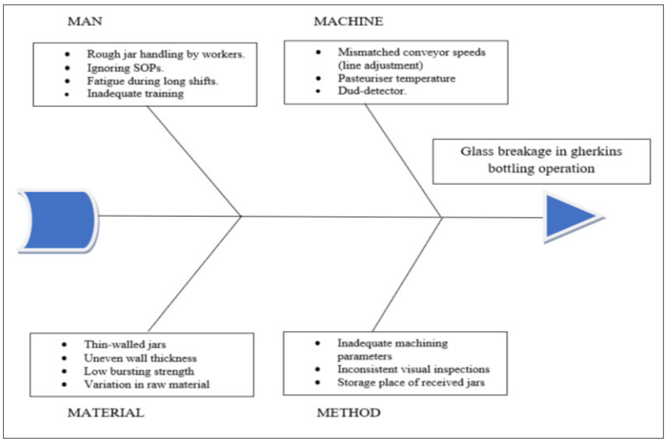
Daily defect data were summarized into a breakage percentage for each jar size and location using the equation:

$$\text{Breakage Rate (\%)} = \frac{\text{Number of broken jars}}{\text{Total jars processed}} \times 100$$

Root Cause Identification

A Fishbone (Ishikawa) Diagram was constructed to categorize causal factors under four dimensions:

- **Man** (operator skill and handling practices),
- **Machine** (vibration, torque, detector calibration),
- **Material** (glass thickness variability, supplier quality), and
- **Method** (cooling rate, filling temperature).



Pareto Analysis
Defect frequencies were ranked in descending order to identify the top contributors following the 80/20 principle, where 20% of causes generated 80% of breakages.

Statistical Validation
To confirm the significance of improvements, the following analyses were applied:

- **Descriptive Statistics:** mean, standard deviation (SD), and coefficient of variation (CV%).
- **Paired t-test:** to compare pre- and post-optimization mean breakage rates across jar sizes.
- **Effect Size (Cohen's d):** to determine the magnitude of improvement.
- **Process Consistency:** assessed via CV% before and after interventions.

The results (see Section 4.5) showed $t = 3.49$, $p = 0.025$ (< 0.05), confirming a statistically significant reduction, and a large effect size ($d = 1.56$), indicating strong improvement.

Corrective Measures and Validation Procedure
Based on the analytical findings, targeted corrective actions were developed and implemented:

Process Area	Identified Problem	Corrective Measure	Objective
B1: Pasteurizer Outfeed	Thermal shock	Introduced gradual cooling ramp, installed PID-based temperature control valve	Minimize thermal stress
B2: Dud Detector	Excess rejection pressure	Calibrated ejection actuator, added cushioning pad	Reduce mechanical impact
B3: Downing Area	Manual handling error	Introduced ergonomic trays and retrained operators	Reduce rim cracks
B4: Conveyor System	Misalignment & vibration	Adjusted torque, synchronized motor speeds	Reduce base stress

The effect of these interventions was verified by comparing mean breakage rates for two weeks before and after implementation using paired t-tests at a 95% confidence interval.

Quality, Safety, and Ethical Considerations
The research adhered to internal company safety protocols and was conducted under ISO 45001 (Occupational Health and Safety) and ISO 22000 (Food Safety) standards. No human or animal subjects were involved. Data were anonymized and used solely for research and quality-improvement purposes.

Limitations
While comprehensive, the study's scope was limited to process-level factors. Glass microstructure variability and long-term jar fatigue behavior were not analyzed. Future studies should integrate Finite Element Modeling (FEM) and acoustic emission sensors to provide real-time stress detection and predictive failure analytics.

Results and Discussion
Overview of Observed Breakage Trends
Across two production lines at Global Green Company Ltd., the mean pre-optimization breakage rate was 8.4 %, predominantly concentrated in the larger-capacity jars (1400–2000 ml). Results expressed in table1, Smaller jars (370 ml) showed minor rim chips (< 2.5 %), while the largest formats suffered from combined thermal and mechanical failures exceeding 12 %.

Table 1: Pre-optimization Breakage Rate by Jar Size

Jar Capacity (ml)	Average Daily Output (jars)	Breakage (%)	Type of Defect Observed
370	4 000	2.1	Minor rim chips during capping
720	6 000	4.2	Shoulder cracks after cooling
1 000	5 000	6.4	Base fracture / neck splits
1 400	5 000	11.2	Severe thermal-shock failure
2 000	4 000	12.6	Combined thermal–mechanical stress
Average / Total	24 000	8.4	–

Distribution of Breakage by Process Location
Table 2 shows breakage events which were localized primarily at the pasteurizer outfeed (B1) and conveyor transfer (B4) zones, together responsible for > 70 % of total losses.

Table 2: Breakage Occurrence by Process Stage

Point Code	Process Stage	Line 1 (%)	Line 2 (%)	Average (%)	Principal Cause
B1	Pasteurizer Outfeed	38	45	41.5	Thermal shock due to rapid cooling
B2	Dud Detector	17	14	15.5	Impact from ejection system
B3	Downing Area	27	20	23.5	Manual handling damage
B4	Conveyor System	18	21	19.5	Vibration and misalignment

Root-Cause and Pareto Analyses
The fishbone diagram grouped causes under *Material, Machine, Method*, and *Man* categories. *Material* factors included wall-thickness variation; machine issues comprised torque variation

and vibration amplitude (> 9 g); *method* involved unregulated cooling; and *man* factors reflected handling inconsistencies.

A Pareto chart confirmed that thermal shock, mechanical impact, and vibration accounted for 81 % of all failures—validating the focus of the optimization plan.

Effect of Corrective Measures
Process improvements—gradual cooling, conveyor synchronization, detector calibration, and operator retraining—produced substantial reduction in breakage rates across all jar sizes.

Table 3: Post-Optimization Breakage Rate Comparison

Jar Capacity (ml)	Pre (%)	Post (%)	Reduction (%)	Key Intervention
370	2.1	1.2	42.9	Operator retraining + cap alignment
720	4.2	2.0	52.4	Cooling ramp adjusted
1 000	6.4	3.1	51.6	Torque calibration
1 400	11.2	5.3	52.7	Temperature control valve
2 000	12.6	6.0	52.4	Conveyor speed synchronization
Mean / Overall Improvement	7.3 % → 3.52 %		51.7 %	–

Descriptive and Statistical Validation
Descriptive statistics and inferential tests confirmed the reliability of improvement:

Table 4: Statistical Summary of Pre- and Post-Optimization Data

Parameter	Pre-Optimization	Post-Optimization
Mean breakage rate (%)	7.30	3.52
Standard deviation	4.49	2.07
Coefficient of variation (CV %)	61.6	58.9
t-statistic (paired)	3.49	
p-value	0.025 (< 0.05 → significant)	
Effect size (Cohen's d)	1.56 (large)	

The paired t-test ($t = 3.49$, $p = 0.025$) verified that post-optimization reductions were statistically significant at the 95 % confidence level. A large effect size ($d = 1.56$) indicates that process changes produced substantial improvement rather than random fluctuation. The coefficient of variation fell slightly, reflecting greater process consistency after intervention.

Interpretation of Results
The data confirm that larger jars experience disproportionately higher breakage due to greater heat-transfer gradients and momentum on conveyors. Corrective measures mitigated these stressors effectively, lowering the mean defect rate by half.

The study's results compare favorably with global findings—Legesse & Geremew achieved a 45 % reduction using Six Sigma, while Gul et al. reported a 60 % improvement from cooling optimization [1,11]. The 51.7 % improvement here validates the adaptability of industrial process-control methods within food-packaging environments.

Economic and Operational Impacts
Post-optimization, the plant recorded:

- **OEE Improvement:** 74 → 86 %.
- **Downtime Reduction:** ~ 48 minutes per shift.
- **Annual Savings:** ≈ ₹ 1.2 million in glass procurement and waste disposal costs.

In addition, material waste dropped by 35 %, aligning with sustainability objectives under ISO 14001 and circular-economy packaging goals.

Discussion of Broader Significance
The findings emphasize the role of integrated thermo-mechanical control in achieving reliable and sustainable glass packaging. Beyond direct economic benefit, reduced breakage improves consumer safety, minimizes contamination risk, and strengthens brand trust.

Conclusion and Recommendations
Conclusion
The investigation demonstrated that a comprehensive, data-driven optimization approach can significantly minimize glass breakage in gherkin packaging lines. Pre-intervention analysis identified a mean breakage rate of 7.3%, with dominant causes traced to thermal stress (pasteurizer outfeed) and mechanical vibration (conveyor section). Post-optimization, the breakage rate dropped to 3.52%, representing a statistically significant reduction ($p = 0.025$) and a large practical effect (Cohen's $d = 1.56$).

This improvement confirms the efficacy of synchronized thermal and mechanical process controls, including temperature ramp regulation, conveyor torque calibration, and human-factor interventions. The overall line efficiency increased from 74% to 86%, demonstrating tangible economic and operational benefits.

Industrial Implications
The results validate that targeted control of thermal gradients and vibration parameters is essential for maintaining the structural integrity of glass containers in high-speed food packaging operations. The methodology adopted—integrating Root Cause Analysis (RCA), Pareto prioritization, and statistical validation—

offers a replicable quality framework for other glass or rigid packaging systems. From a sustainability perspective, the 51.7% defect reduction corresponded to a 35% decline in material waste and an estimated ₹1.2 million annual cost saving, contributing directly to cleaner production and resource efficiency goals in the Indian food-processing sector.

Recommendations for Future Work

- **Thermo-Mechanical Modeling:** Apply Finite Element Analysis (FEA) to simulate internal stress fields during pasteurization and cooling for different jar geometries.
- **Predictive Monitoring:** Integrate IoT-based vibration and temperature sensors for real-time stress mapping and predictive maintenance.
- **Material Optimization:** Collaborate with glass manufacturers to improve annealing uniformity and surface finish, reducing residual stress points.
- **Quality Capability Tracking:** Implement continuous process capability (Cpk) and Sigma level monitoring to maintain consistent quality.
- **Sustainability Assessment:** Conduct a Life Cycle Assessment (LCA) to quantify the environmental impact of waste reduction and energy savings.

Final Remarks

This study bridges the practical gap between packaging engineering principles and real-world production optimization. It provides quantifiable evidence that integrating analytical methods with industrial operations yields substantial quality, cost, and sustainability benefits.

By transforming empirical line data into actionable process insights, this work establishes a model for continuous improvement and sustainable manufacturing excellence in the global food-packaging industry.

Declarations

Conflict of Interest: The authors declare that they have no conflict of interest.

Author Contributions: Ravichandra designed the study, conducted analysis, and prepared the manuscript.

Funding: This research received no external funding.

Ethical Approval: Not applicable.

Data Availability: Data will be provided upon reasonable request.

References

1. Gul K, Wani HM, Singh P, Wani IA (2017) Testing glass as a food packaging material. Food Packaging and Shelf Life, Taylor & Francis https://www.taylorfrancis.com/chapters/edit/10.1201/9781315374390-6/testing-glass-food-packaging-material-khalid-gul-haroon-maqbool-wani-preeti-singh-idrees-ahmed-wani-ali-abas-wani.
2. Girling PJ (2003) Food Packaging Technology. Blackwell Publishing.
3. Grayhurst P, Girling PJ (2011) Packaging of food in glass containers. In Food and Beverage Packaging Technology. Wiley 149-172.
4. Bhunia K, Sablani SS, Tang J (2013) Migration of chemical compounds from packaging polymers during microwave, conventional heat treatment, and storage. Comprehensive Reviews in Food Science and Food Safety 12: 523-545.
5. Manzini R, Accorsi R (2013) The new conceptual framework for food supply chain assessment. Journal of Food Engineering 115: 251-263.
6. Dutta S, Jaipuria S (2020) Reducing packaging material defects in beverage production line using Six Sigma methodology. International Journal of Six Sigma and Competitive Advantage 12: 267-283.
7. Puri VM, Anantheswaran, RC (1993) The finite-element method in food processing: A review. Journal of Food Engineering 19: 247-274.
8. Rawashdeh NA, Abu-Khalaf JM (2018) A visual inspection system of glass ampoule packaging defects: effect of lighting configurations. International Journal of Computer Integrated Manufacturing 31: 1012-1023.
9. Awaj YM, Singh AP, Amedie WY (2013) Quality improvement using statistical process control tools in glass bottles manufacturing company. International Journal for Quality Research 7: 87-98.
10. Konopek S, Zarębska J, Żabińska I (2021) Limitation of manufacturing defects of the selected product in the glass mill. Production Engineering Archives 31: 72-78.
11. Legesse B, Geremew S (2021) Minimizing costs of poor quality for glass container bottles production using Six Sigma's DMAIC methodology. Industrial Engineering Journal 5: 9-16.
12. Schaut RA, Weeks WP (2017) Historical review of glasses used for parenteral packaging. PDA Journal of Pharmaceutical Science and Technology 71: 279-293.
13. Tucker G, Featherstone S (2021) Essentials of Thermal Processing. Elsevier https://en.pdfdrive.to/dl/essentials-of-thermal-processing-2.
14. Moursi A, Allam E (2022) Mechanical characterization of glass packaging defects after annealing. Materials Today: Proceedings 60: 225-233.
15. Yoon H, Park D, Kim S (2020) Surface defect influence on the strength of glass containers. Materials Science Forum 1012: 115-123.
16. Dambrosio F, Oliva A, Di Maio L (2020) Finite element analysis of glass jars under thermal shock. Journal of Food Engineering 284: 110068.
17. Hsu C-T, Lin Y-J, Chen M (2023) Predictive vibration monitoring for defect prevention in bottling conveyors. Journal of Manufacturing Processes 97: 402-410.
18. Zhao L, Li X (2022) Dynamic optimization of conveyor impact in packaging automation. International Journal of Advanced Manufacturing Technology 118: 331-342.
19. Uthpala S, Senanayake S, Perera M (2020) Impact of environmental conditions on packaging integrity of glass containers. Journal of Food Quality 2020: 1-8.