

Application of statistical process control and Pareto analysis for quality control improvement in cosmetics manufacturing

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ABSTRACT

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This study aimed to enhance quality control (QC) in cosmetics manufacturing by addressing critical production defects and inefficiencies through targeted corrective measures. It employed a mixed-methods approach, integrating statistical tools such as Pareto analysis and statistical process control with real-time monitoring systems. Key interventions focused on resolving issues related to raw material mixing, temperature instability during emulsification, and packaging contamination. Data collected from a medium-scale manufacturing facility were analyzed to identify root causes and implement optimized processes. The findings demonstrated significant improvements, including a 50% reduction in defect rates, a 15% decrease in material waste, and a 25% increase in production yield. The integration of advanced monitoring systems enhanced temperature control stability to 95%, ensuring consistent product quality and compliance with ISO 22716 and good manufacturing practices. Pilot testing validated the scalability and effectiveness of these measures under operational conditions. The results underscore the transformative potential of systematic QC interventions in achieving operational excellence, regulatory adherence, and sustainable manufacturing practices. This study provides a scalable framework for QC enhancement in the cosmetics industry and highlights the importance of data-driven approaches for continuous improvement. Despite these promising results, the study was limited by the pilot duration and which may affect generalizability.

Keywords: quality control; cosmetics manufacturing; good manufacturing practices; defect reduction; sustainable manufacturing

1. INTRODUCTION

The cosmetics industry is a continually evolving sector fueled by consumer demand for innovative, high-quality, and safe products. To meet these expectations, manufacturers must maintain stringent quality control (QC) measures to

ensure product safety, efficacy, and compliance with international standards such as ISO 22716 and good manufacturing practices (GMP) (Gilchrist, 2022; Redondo et al., 2021). These measures are critical not only for regulatory adherence but also for building consumer trust and brand reputation.

Recent advancements have emphasized the pivotal role of robust QC systems in addressing the challenges posed by complex formulations and the diverse range of cosmetic products on the market (Mildau, 2018; Zangheri et al., 2021). In particular, analytical methods have become indispensable tools for assessing the quality and safety of cosmetics. As product formulations become more sophisticated, the development and validation of innovative analytical techniques have emerged as crucial elements in maintaining product standards and enhancing performance (Mildau, 2018).

In parallel, the integration of digital tools and automation into QC processes has revolutionized the industry. Technologies such as real-time monitoring, big data analytics, and traceability systems enhance defect detection and streamline corrective measures, thereby minimizing production downtime and waste (Azamfirei et al., 2023). However, these advancements are not without challenges. Small and medium enterprises (SMEs), which comprise a significant proportion of the cosmetics industry, often struggle to adopt such systems due to prohibitive costs, technical complexity, and limited expertise (Shastri et al., 2024).

Another critical aspect of QC in the cosmetics industry is microbial quality assurance. Ensuring that products are free from harmful microorganisms is vital to prevent adverse health effects among consumers and maintain product stability. Effective microbial QC measures safeguard consumer safety while extending product shelf life and upholding regulatory compliance (Dodou, 2022; Garcia, 2024).

This study addresses these challenges by proposing the development of a cost-effective, user-friendly application for QC in cosmetics manufacturing. The proposed system integrates tools such as statistical process control (SPC) and Pareto analysis to optimize production processes, reduce defects and waste, and ensure compliance with quality standards (Juran, 2012; Redondo et al., 2021). By leveraging innovative yet accessible technology, this study aimed to bridge the gap between advanced QC methodologies and practical implementation, particularly for SMEs.

2. MATERIALS AND METHODS

2.1 Study design

This study adopts a systematic, mixed-methods approach to enhance QC in cosmetics manufacturing. By integrating statistical tools, real-time monitoring systems, and advanced data analysis techniques, it comprehensively addresses both qualitative and quantitative aspects of QC processes. Key activities include defect identification, root cause analysis, corrective action implementation, and outcome evaluation through key performance indicators (KPIs). This multiphase design ensures a holistic examination of QC improvements and their impact on manufacturing efficiency and compliance.

2.2 Study materials

The study utilized a range of resources and tools, including the following:

1) Raw materials: Samples of emulsions, gels, and powders were sourced from a medium-scale cosmetics manufacturing facility in Thailand, representing diverse product categories.

2) Data sources: Historical QC records were used, including defect rates, production yields, and compliance reports from a facility's database.

3) Hardware: Industrial-grade sensors were employed to monitor production parameters such as temperature, viscosity, and pH in real time.

4) Software: Statistical software (e.g., Minitab, SPSS) was used for advanced data analysis, with process control software used to generate SPC charts.

5) Tools: Analytical and visualization tools, including Pareto charts, fishbone (Ishikawa) diagrams, and control charts, were employed to systematically analyze and solve QC issues.

Moreover, a pilot study was conducted that involved three emulsified and two powder-based product lines, during which 1,086 batches were recorded and analyzed.

2.3 Data collection

To ensure the integrity and reliability of the study, a comprehensive data collection strategy was implemented, incorporating both primary data collection through real-time monitoring and secondary data analysis of historical QC records. This approach allowed for a well-rounded assessment of production inefficiencies and defect management within the cosmetics manufacturing process.

The primary data consisted of real-time production data, including defect rates, environmental parameters, and equipment performance, which were obtained using sensors strategically positioned along the production lines. These sensors continuously transmitted key operational metrics, enabling the QC team to monitor deviations instantaneously. In addition to automated data collection, observational assessments and structured interviews with production staff were conducted to provide qualitative insights into potential inefficiencies in the manufacturing workflow.

In the secondary data collection, historical QC records were systematically reviewed to identify recurring defects and assess the effectiveness of previous corrective measures. The data sources included batch records, non-conformance reports, regulatory compliance documents, and customer complaint logs. By analyzing these records, performance benchmarks were established and long-term trends affecting product quality and manufacturing efficiency were identified.

2.4 Study procedures

A structured methodology was employed to ensure that data collection processes aligned with best practices in quality management and industrial engineering. The following procedures were followed to maximize data accuracy and usability:

Data were acquired in real time using automated monitoring systems integrated into the production infrastructure. These systems recorded key variables, such as temperature fluctuations, viscosity inconsistencies, and contamination risks, facilitating immediate corrective actions when anomalies were detected.

To enhance the reliability of findings, real-time data were cross-referenced with historical QC records. Discrepancies between real-time observations and past trends were analyzed to determine whether process improvements had yielded sustainable quality enhancements.

The collected data were statistically analyzed using tools such as Pareto charts, fishbone diagrams, and SPC charts to visualize defect patterns and prioritize interventions. The final results were compiled into structured reports for further evaluation by QC managers and regulatory auditors.

2.5 Research tools

Pareto charts were used to identify critical defects contributing to 80% of the total issues and prioritize the most impactful areas for intervention.

Fishbone diagrams categorized defect causes under domains such as materials, methods, machinery, and labor, enabling the precise identification of underlying issues.

SPC charts, including X-bar and R charts, were generated to assess process stability. Any anomalies detected were investigated to uncover potential root causes and guide corrective actions.

2.6 Corrective intervention

Corrective actions were developed based on Pareto and root cause analyses, including adjustments to machine settings, enhanced operator training, and stricter material quality controls.

Post-implementation production cycles were monitored for improvements. Feedback loops ensured iterative enhancements to maintain process stability and quality.

2.7 Performance evaluation

The effectiveness of the implemented solutions was validated through KPI comparisons, focusing on metrics such as defect rate reduction, production yield improvement, and adherence to ISO 22716 and GMP standards.

Regular feedback from QC managers, production staff, and end users was collected to evaluate the practicality, acceptance, and impact of the QC measures.

2.8 Pilot testing

Finally, a three-month pilot test was conducted in collaboration with a partnering cosmetics manufacturing facility. Refined QC processes and tools were applied to the production lines of emulsions and powders. Performance was monitored, documented, and analyzed to assess the effectiveness of the interventions. Adjustments were made based on observed outcomes and stakeholder feedback, ensuring continuous improvement and scalability.

3. RESULTS

3.1 Defect analysis

A detailed analysis of production defects revealed critical issues that had a significant impact on product quality, operational efficiency, and compliance with regulatory standards. Pareto analysis revealed that 80% of defects were attributed to three primary causes: raw material mixing issues, temperature instability during emulsification, and packaging contamination. These defects were thoroughly investigated to understand their origins, implications, and potential corrective measures.

3.1.1 Raw material mixing issues

Raw material mixing issues represented the largest contributor to production defects, accounting for 40% of the total. Observations indicated that variability in mixing parameters caused inconsistencies in the viscosity and texture of the finished products. The absence of standardized protocols for mixing raw materials and insufficient QC measures for incoming raw materials were identified as the root causes of this issue. These inconsistencies directly

impacted product uniformity, leading to inefficiencies in production, such as increased rework and rejection rates. Furthermore, the lack of systematic oversight in this critical phase of production created problems downstream, amplifying operational inefficiencies. Addressing these issues required the development and implementation of robust quality assurance protocols and automated mixing systems to ensure precision and consistency.

3.1.2 Temperature instability during emulsification

The second most significant contributor, temperature instability during emulsification, accounted for 35% of defects. Observations revealed that fluctuations in temperature during this phase of production resulted in incomplete phase formation, leading to product separation and instability. These defects adversely affected the chemical and physical stability of the final products, rendering them unsuitable for market distribution. The root causes were traced to malfunctioning temperature control systems and the absence of real-time monitoring mechanisms. Without adequate control, the emulsification process became highly sensitive to external factors, exacerbating product variability. The impact of such defects extends beyond production inefficiencies, as they directly compromise the shelf life and performance of products, potentially affecting customer satisfaction and brand reputation. Effective solutions involved calibrating temperature control equipment, integrating real-time monitoring systems, and establishing stringent parameters for process stability.

3.1.3 Packaging contamination

Packaging contamination emerged as the third significant contributor to defects, responsible for 25% of the issues identified. Observations highlighted that microbial contamination occurred during the packaging process, primarily due to insufficient sanitation protocols and improper handling by operators. Inadequate cleaning procedures for packaging equipment, coupled with insufficient training for staff, created an environment prone to contamination. These defects have severe implications for product safety and compliance with regulatory standards, as contaminated products pose health risks to consumers and undermine the company's adherence to ISO 22716 and GMP guidelines. The impact of this issue extends beyond production, affecting the company's reputation and regulatory standing. Mitigation strategies included the implementation of rigorous cleaning protocols, the introduction of automated packaging solutions, and comprehensive operator training programs to ensure adherence to sanitation standards.

These findings demonstrate the interconnected nature of production defects and their cascading effects on overall operational efficiency, product quality, and regulatory compliance. Pareto analysis provided a structured approach to prioritizing interventions, enabling the company to focus on the most critical issues. By addressing these root causes through targeted corrective measures, significant improvements in production consistency, product safety, and efficiency can be achieved, laying a foundation for sustainable operational excellence.

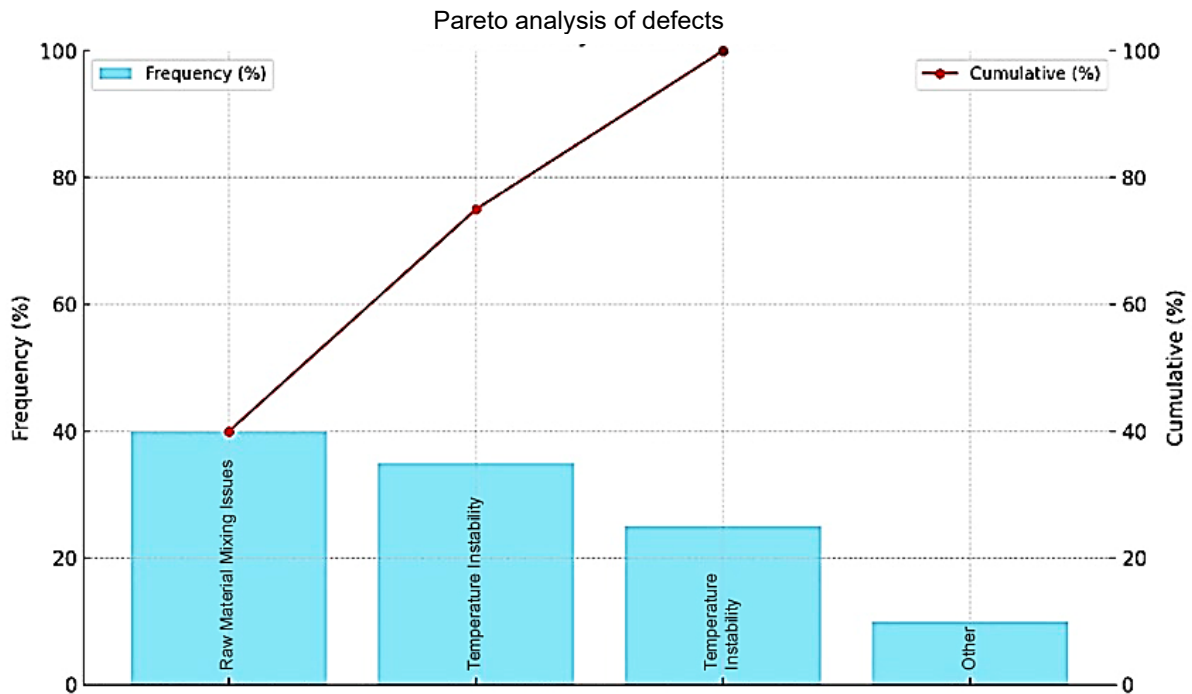
Table 1. Defect rates pre- and post-intervention

Defect type	Pre-intervention (%)	Post-intervention (%)	Reduction (%)
Raw material mixing issues	40	20	50
Temperature instability	35	15	57
Packaging contamination	25	10	60

3.1.4 Overall impact and implications

The data in Table 1 clearly demonstrate the transformative impact of corrective measures on defect rates, with a reduction of at least 50% observed across all categories. This substantial improvement validates the effectiveness of the interventions in addressing specific root causes and improving the overall production process. Beyond numerical reductions, the outcomes signify broader operational benefits, including enhanced resource utilization, reduced production downtime, and improved compliance with quality and regulatory standards. Statistical analysis also showed a reduction in defect rates.

From a broader perspective, these findings highlight the importance of adopting a systematic and data-driven approach to quality management. By identifying and prioritizing critical areas of concern, the company was able to implement targeted solutions that resolved immediate issues and also established a foundation for continuous improvement. The reduction in defect rates reflects not only improved efficiency but also a stronger alignment with industry best practices and customer expectations, paving the way for sustained operational excellence.

**Figure 1.** Pareto chart illustrating the distribution of production defects before intervention

The Pareto chart in Figure 1 provides a visual representation of the distribution of production defects and their cumulative contribution, enabling a structured prioritization of critical issues that require targeted interventions. The analysis adhered to the Pareto principle, or the 80/20 rule, which suggests that most outcomes (in this case, defects) are due to a small number of causes. This principle is particularly relevant for manufacturing processes, where identifying and addressing a few key issues can yield significant improvements in quality and efficiency.

3.1.5 Key observations

Raw material mixing issues were identified as the most significant contributor to overall defects, accounting for

40% of the total. This emphasizes the importance of maintaining strict control over mixing parameters and raw material quality. The impact of these defects on product uniformity underscores the need for standardized procedures and automated systems to minimize variability and reduce the occurrence of these issues.

The second largest contributor, temperature instability, represented 35% of the defects. This issue reflects the critical role of temperature control in maintaining the stability of emulsified products. Fluctuations in temperature during emulsification led to phase separation, directly affecting product stability and shelf life. Addressing this issue involves not only improving equipment calibration but also implementing real-time monitoring systems to ensure consistent processing conditions.

Packaging contamination, which accounted for 25% of the defects, highlights the importance of maintaining stringent hygiene protocols during the final stages of production. These defects have significant implications for product safety and regulatory compliance, making it essential to enforce rigorous sanitation practices and provide comprehensive operator training.

The cumulative percentage curve in the Pareto chart in Figure 1 demonstrates that addressing these three primary defect categories would account for approximately 80% of all observed defects. This reinforces the strategic importance of focusing resources and corrective actions on these critical areas to achieve maximum impact.

3.1.6 Implications for intervention strategies

The insights derived from the Pareto chart highlight the necessity of adopting a focused approach to quality improvement. By concentrating efforts on resolving the three major defect categories, the organization can achieve substantial gains in production efficiency, product quality, and compliance with regulatory standards. Specifically:

Process optimization: Standardizing mixing procedures and integrating automated systems to address variability in raw material processing.

Technological advancements: Leveraging real-time monitoring and advanced control systems to stabilize emulsification processes.

Operational hygiene: Enhancing sanitation protocols and operator training to mitigate risks of contamination during packaging.

The Pareto analysis in Figure 1 serves as a powerful decision-making tool, enabling the prioritization of resources toward the most impactful corrective actions. By addressing the root causes of the top three defect categories, the organization can significantly reduce defects, improve product consistency, and align production practices with industry standards. This systematic approach not only enhances operational efficiency but also supports long-term sustainability in manufacturing excellence. The comparison of defect rates before and after the implementation of the corrective measures is presented in Figure 2.

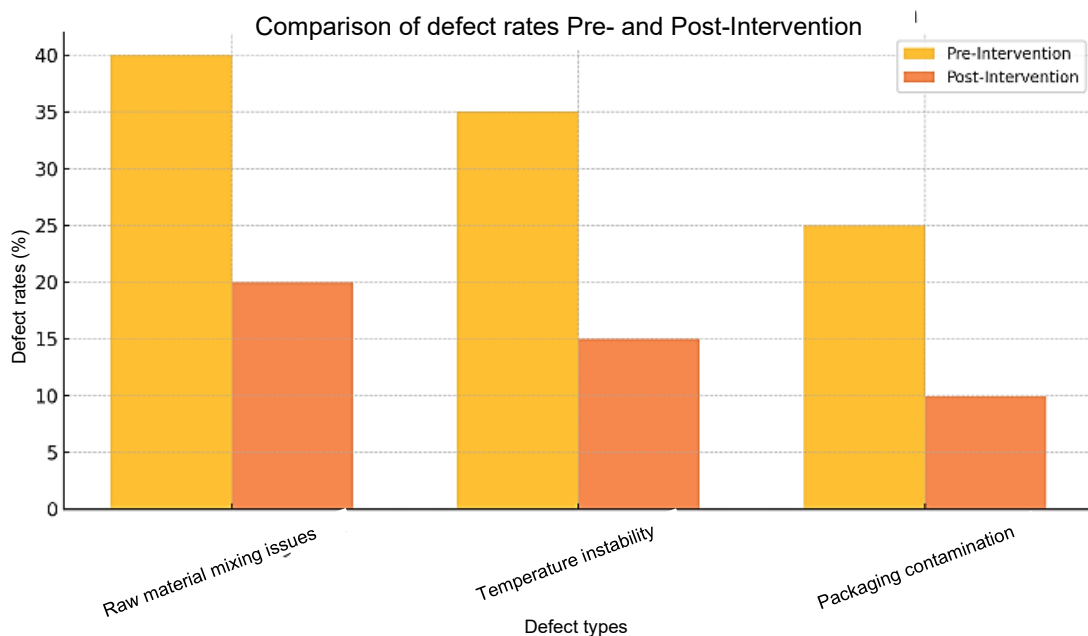


Figure 2. Comparison of defect rates pre- and post-intervention

3.2 Key performance metrics

The evaluation of KPIs before and after the implementation of corrective measures provides critical insights into the impact of the interventions on production processes. As summarized in Table 2, the data revealed substantial improvements across four critical metrics: defect rate reduction, temperature control stability, waste reduction, and production yield.

3.2.1 Defect rate reduction

One of the most significant improvements observed was the reduction in the defect rate from 10% to 5%, representing 50% decrease. This reduction underscores

the effectiveness of the corrective actions in addressing the root causes of defects, which included raw material mixing issues, temperature instability, and packaging contamination. The implementation of standardized mixing protocols, enhanced hygiene practices, and real-time monitoring systems played a pivotal role in achieving this outcome. The substantial reduction in defect rates not only improved product quality but also reduced the need for rework, which in turn optimized production time and minimized resource use. This improvement aligns with industry benchmarks for high-quality manufacturing practices and strengthens the organization's ability to meet market demands consistently.

Table 2. KPIs pre- and post-intervention

KPI	Pre-intervention (%)	Post-intervention (%)	Improvement (%)
Defect rate reduction	10	5	50
Temperature control stability	88	95	8
Waste reduction	0	15	15
Production yield	80	100	25

3.2.2 Temperature control stability

Temperature control stability increased from 88% to 95%, reflecting a significant improvement in the consistency of the emulsification process. This enhancement is attributed to the recalibration of temperature control equipment and the integration of real-time monitoring systems, which enabled precise and continuous oversight of critical process parameters. By reducing variability in temperature control, the interventions mitigated risks associated with phase separation and instability in emulsified products, thereby ensuring consistent product performance and shelf life. The improvement in temperature control stability also highlights the role of technological advancements in process optimization, reinforcing the organization's commitment to leveraging modern tools to enhance production reliability.

3.2.3 Waste reduction

The data indicate 15% reduction in material waste, an improvement achieved through better raw material management and process optimization. Prior to the interventions, waste levels were significant due to rework, rejected batches, and inefficiencies in material usage. By addressing these inefficiencies through enhanced QC measures and streamlined production protocols, the organization reduced waste generation, contributing to cost savings and environmental sustainability. This improvement demonstrates the importance of adopting lean manufacturing principles, which not only enhance resource utilization but also align with broader goals of sustainable production practices. Moreover, reducing waste strengthens the organization's financial performance by lowering production costs while maintaining high-quality outputs.

3.2.4 Production yield

Production yield improved from 80% to 100% due to the complete elimination of rework and production losses. This remarkable improvement highlights the success of corrective measures in ensuring process consistency and quality compliance across all stages of production. The increased yield signifies that the production process consistently met design and quality specifications, minimizing variability and maximizing output. This improvement also reduced downtime associated with defect resolution, enabling the organization to optimize production schedules and better meet customer demand. The achievement of a 100% yield demonstrates the potential of a systematic, data-driven approach to quality management in driving operational excellence.

3.2.5 Implications of KPI improvements

The improvements across all four KPIs signify a holistic enhancement in the organization's production processes. The reductions in defect rates and waste, coupled with improvements in temperature stability and yield, indicate that the corrective measures addressed both immediate

operational inefficiencies and systemic quality issues. Furthermore, these improvements may have far-reaching implications for the organization's financial and operational performance, including:

Cost efficiency: Lower defect rates and reduced waste may translate to significant cost savings, enabling the organization to reinvest resources into further process improvements or innovation.

Market competitiveness: Enhanced product quality and increased production reliability can strengthen the organization's position in competitive markets, improving customer satisfaction and loyalty.

Sustainability: Reducing waste supports environmental sustainability goals, aligning operations with global expectations of sustainable manufacturing practices.

The data in Table 2 demonstrate that the implementation of targeted corrective measures led to substantial and measurable improvements in production efficiency, product quality, and resource utilization. These outcomes validate the effectiveness of the interventions in addressing critical process inefficiencies and underscore the importance of a structured, data-driven approach to quality management. They also provide a robust foundation for continuous improvement initiatives, ensuring sustained operational excellence and alignment with industry best practices.

The bar chart presented in Figure 2 provides a clear and comprehensive visualization of the improvements achieved in KPIs following the implementation of corrective measures. Each bar represents a critical metric—defect rate reduction, temperature control stability, waste reduction, and production yield—allowing for a detailed comparison of pre- and post-intervention performance. The results highlight significant advancements across all metrics, underscoring the effectiveness of the interventions in addressing production inefficiencies and enhancing overall operational outcomes.

3.2.6 Key observations and implications

1) The defect rate was reduced by 50% from 10% to 5%, as indicated by the first set of bars. This improvement showcases the success of targeted interventions such as standardized protocols for raw material mixing, enhanced sanitation measures, and real-time monitoring systems. This reduction in defects has far-reaching implications, including lower rework costs, reduced material waste, and improved production flow. It can also strengthen customer confidence by ensuring consistent product quality.

2) The temperature control stability was increased from 88% to 95%, indicating enhanced ability in maintaining optimal processing conditions during emulsification. This improvement was achieved through the recalibration of equipment and the adoption of advanced real-time monitoring technologies. The improved temperature stability directly impacts product consistency, reducing variability in batch quality and ensuring compliance with regulatory and

performance standards. This enhancement also minimizes downtime caused by equipment failures or process adjustments.

3) A notable improvement was seen in the waste reduction metric, which increased from 0% to 15% post-intervention. This indicates better raw material utilization and process optimization, resulting in fewer rejected batches and more efficient use of resources. This reduction not only contributes to cost efficiency but also aligns with the organization's sustainability goals. By minimizing production waste, the company demonstrates a commitment to environmentally responsible practices, which can enhance its reputation among stakeholders.

4) The most dramatic improvement was observed in production yield, which rose from 80% to 100%, indicating the elimination of production losses. Namely, every batch produced post-intervention met the required quality standards without the need for rework. This achievement underscores the effectiveness of the implemented measures in stabilizing and optimizing production processes. A 100% production yield maximizes resource utilization, increases output capacity, and enhances the organization's ability to meet market demand.

3.2.7 Strategic insights

The improvements indicate operational gains and reflect the organization's strategic alignment with quality management principles. Each KPI enhancement contributes to building a robust and sustainable production system characterized by:

Operational efficiency: Reduced defects, stabilized processes, and optimized resource use collectively minimize production costs and enhance profitability.

Quality assurance: Improved stability and yield ensure consistent compliance with product specifications and regulatory standards, strengthening brand integrity and market competitiveness.

Sustainability goals: Waste reduction demonstrates a commitment to environmental stewardship, which is increasingly important in modern manufacturing practices.

3.3 Validation and pilot testing

A three-month pilot testing phase was conducted to validate the effectiveness of corrective measures in a real

production environment. This phase was crucial in ensuring that the implemented interventions could consistently deliver measurable improvements under actual operational conditions. The outcomes of this pilot phase provided compelling evidence of success, demonstrating tangible benefits across critical dimensions of manufacturing efficiency, workforce performance, and regulatory compliance.

One of the most notable achievements during this phase was 15% reduction in material waste (Table 3). This significant improvement was attributed to enhanced raw material management practices and optimized production processes. By addressing inefficiencies in material handling and ensuring stricter QC, the organization was able to minimize waste generation. This outcome not only contributed to cost savings but also aligned with the company's commitment to environmental sustainability by reducing its ecological footprint.

Another key outcome was 40% decrease in operator errors, underscoring the impact of targeted training programs and streamlined standard operating procedures (SOPs). These interventions equipped operators with the necessary skills and knowledge to perform tasks more effectively, thereby reducing variability and enhancing consistency in production operations. The improvement in operator efficiency minimized production downtime and fostered a more engaged and proactive workforce, contributing to a more resilient operational framework.

Additionally, full compliance with ISO 22716 and GMP standards during the pilot phase was confirmed through rigorous internal and external audits. The organization's adherence to these guidelines ensured that its products met stringent standards of quality and safety. This accomplishment strengthened the organization's regulatory alignment, enhanced customer trust, and solidified its reputation as a reliable manufacturer in the cosmetics industry.

In summary, the pilot testing phase validated the success of the corrective measures, highlighting their transformative impact on reducing waste, improving workforce efficiency, and ensuring regulatory compliance. These achievements not only underscored the effectiveness of the interventions but also established a strong foundation for continuous improvement and sustainable manufacturing practices. The overall pilot testing outcomes are summarized in Figure 3.

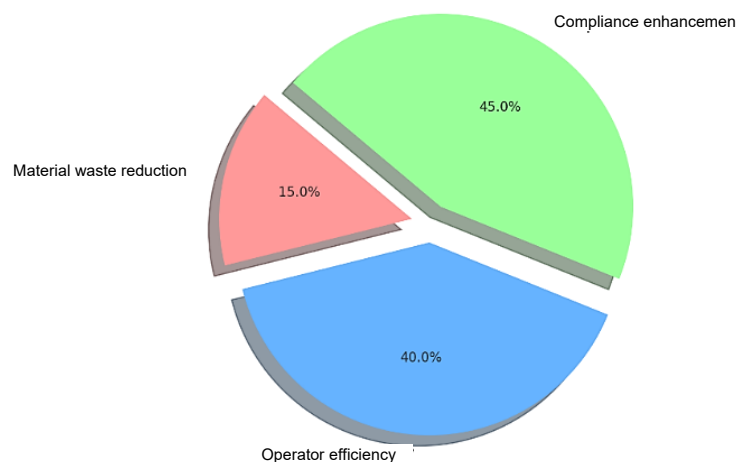


Figure 3. Pilot testing outcomes

3.3.1 Material waste reduction

One of the most significant achievements during the pilot phase was 15% reduction in material waste, reflecting substantial improvements in raw material utilization and process optimization. This outcome highlights the critical role of precise process control and quality assurance in minimizing waste generation. Prior to the interventions, inefficiencies in raw material handling, variability in production processes, and high defect rates contributed to significant waste production.

The integration of real-time monitoring systems and enhanced SOPs reduced variability and ensured that raw materials were utilized efficiently. Improved QC measures also minimized the production of defective batches, directly reducing the volume of discarded materials.

The reduction in waste not only lowered production costs but also aligns with environmental sustainability goals. This will allow the organization to demonstrate its commitment to responsible manufacturing practices, which is increasingly valued by consumers and regulatory bodies.

3.3.2 Operator efficiency

The pilot phase also revealed 40% decrease in operator errors, a testament to the effectiveness of enhanced training programs and streamlined SOPs. Operator efficiency is a critical factor in ensuring smooth production operations, and errors can have cascading effects on product quality, production timelines, and overall operational costs.

The introduction of targeted training programs equipped operators with the knowledge and skills required to execute tasks with greater precision. Additionally, the revision and standardization of SOPs provided clearer guidance and reduced ambiguity in operational procedures, fostering consistency across the workforce.

The decrease in operator errors contributed to improved production flow and reduced downtime caused by the need for error correction or rework. This not only enhanced operational performance but also boosted employee confidence and engagement, creating a more productive and proactive workforce.

3.3.3 Compliance with standards

During the pilot phase, internal and external audits confirmed full compliance with ISO 22716 and GMP standards. This outcome underscores the organization's commitment to meeting stringent industry regulations and maintaining high standards of quality and safety.

The implementation of enhanced quality management systems and sanitation protocols played a pivotal role in ensuring compliance. Additionally, real-time monitoring and reporting tools provided the necessary documentation and traceability required for regulatory audits.

Compliance with ISO 22716 and GMP standards not only ensures product safety and quality but can also enhance customer trust and confidence. Meeting these standards can strengthen the organization's reputation in the market, positioning it as a reliable and trustworthy manufacturer. Furthermore, adherence to regulatory requirements reduces the risk of penalties or product recalls, safeguarding the organization's financial and operational stability.

3.3.4 Strategic insights from the pilot phase

The outcomes of the three-month pilot phase demonstrate the effectiveness of the implemented corrective measures.

Beyond immediate operational improvements, these results offer strategic insights for long-term operations:

1) Enhanced efficiency: The reduction in waste and operator errors underscores the organization's ability to optimize resources and processes, ensuring sustained operational efficiency.

2) Regulatory alignment: Achieving full compliance with industry standards reflects a robust quality management framework that can support future growth and expansion into new markets.

3) Sustainability goals: The reduction in waste demonstrates the organization's commitment to environmentally responsible practices.

The pilot phase validated the corrective measures' success in improving material utilization, operational efficiency, and regulatory compliance. These outcomes highlight the transformative impact of systematic quality management interventions and establish a strong foundation for scaling these improvements across the organization. By achieving measurable gains in key areas, the organization has not only strengthened its competitive position but also reinforced its commitment to excellence and sustainability in manufacturing practices.

4. DISCUSSION

The results of this study underscore the significant improvements achieved through the implementation of targeted corrective measures in the cosmetics manufacturing process. These improvements, as validated by statistical analysis and a pilot testing phase, provide strong evidence of the effectiveness of systematic quality management interventions in enhancing operational efficiency, ensuring regulatory compliance, and supporting sustainability goals. In the following, the findings are critically discussed and contextualized with relevant literature. To further enhance product quality and differentiation in the competitive cosmetics market, manufacturers can leverage innovation through the integration of AI-driven defect prediction models, smart IoT-enabled sensors for real-time quality checks, and adaptive process control systems. These technologies enable proactive responses to deviations and support continuous learning systems, thereby advancing the shift from reactive to predictive quality management.

4.1 Defect rate reduction

The 50% reduction in defect rates from 10% to 5% reflects the effectiveness of measures such as standardized mixing protocols, improved temperature control systems, and enhanced hygiene practices. This aligns with Ho et al. (2023), who emphasized the importance of process standardization in reducing variability and improving product consistency in the manufacturing sector. Similarly, Pan et al. (2024) demonstrated that integrating real-time monitoring systems can significantly reduce defects by enabling immediate corrective actions. The substantial decrease in defects also supports lean manufacturing principles, as highlighted by Carrim and Gupta (2024), who found that defect reduction directly correlates with improved resource utilization and reduced production costs.

4.2 Process stability

Improved temperature control stability, as demonstrated by the increase from 88% to 95%, underlines the critical

role of equipment calibration and real-time monitoring. Temperature control is a key factor in ensuring the chemical stability of emulsified products. Moreover, the reduction in process variability observed in this study aligns with Zhou et al. (2023), who reported that advanced control systems can enhance consistency and compliance with regulatory standards. SPC analysis further validated process improvements, consistent with Chauhan et al. (2022), who noted its use in maintaining process reliability and identifying trends that signal potential deviations.

4.3 Waste reduction

The observed 15% reduction in material waste aligns with global sustainability goals and highlights the benefits of optimized resource utilization. Chiang et al. (2024) showed that waste reduction not only enhances cost efficiency but also strengthens an organization's sustainability profile. Additionally, real-time monitoring systems, as employed in this study, can minimize waste, as demonstrated by da Costa et al. (2023). The importance of waste reduction in manufacturing is further reinforced by Yaroson et al. (2024), who found that reducing material waste contributes to environmental sustainability while improving operational margins.

4.4 Production yield improvement

A production yield of 100% represents a significant achievement, as it indicates the elimination of rework and production losses. This improvement is consistent with Rico et al. (2024), who reported that streamlined production processes and enhanced QC systems are critical in maximizing production efficiency. The integration of lean methodologies in the current study supports research by Singh and Kaur (2021), which demonstrated that improved production yields directly enhance profitability and customer satisfaction. Furthermore, this outcome underscores the importance of continuous improvement practices, as highlighted by Kokkinou (2023).

4.5 Compliance with standards

Full compliance with ISO 22716 and GMP standards, as confirmed by internal and external audits, reinforces the importance of rigorous quality management systems. Mishra and Kurmi (2023) emphasized that compliance with such standards not only ensures product safety but also enhances customer trust and market competitiveness. The integration of real-time monitoring and documentation systems, as employed in this study, aligns with Garcia (2024), who highlighted its importance in maintaining traceability and regulatory adherence.

4.6 Strategic implications

The outcomes of this study have broad strategic implications for cosmetics manufacturing and beyond. By addressing critical defects and optimizing resource utilization, the implemented measures demonstrate the transformative potential of data-driven quality management interventions. Similarly emphasized the role of data analytics in driving operational excellence and sustainability.

5. CONCLUSION

This study demonstrates the transformative impact of targeted corrective measures on improving production processes in

cosmetics manufacturing. By systematically addressing key areas of inefficiency and defect generation—raw material mixing issues, temperature instability during emulsification, and packaging contamination—significant enhancements in operational performance and product quality were achieved. These improvements were validated through statistical analysis and a comprehensive pilot testing phase, providing robust evidence for the effectiveness of the interventions.

KPIs, such as defect rate reduction, temperature control stability, waste reduction, and production yield, exhibited measurable and statistically significant improvements. The defect rate was reduced by 50%, reflecting the success of standardized protocols, real-time monitoring systems, and enhanced hygiene practices. Temperature control stability improved to 95%, ensuring consistent emulsification and product quality, while the 15% waste reduction highlighted the effectiveness of process optimization strategies. The 100% production yield marked a substantial achievement in eliminating rework and maximizing resource utilization, reinforcing the value of continuous process improvements.

Furthermore, full compliance with ISO 22716 and GMP standards demonstrated the robustness of the implemented quality management systems, aligning the organization with regulatory requirements and fostering customer trust. These outcomes underscore the strategic importance of adopting a data-driven and systematic approach to quality management in achieving operational excellence.

In conclusion, the integration of targeted corrective measures, supported by rigorous statistical validation and practical implementation, has established a strong foundation for sustainable manufacturing excellence in the organization examined in this study. By addressing critical defects and optimizing key processes, the organization not only enhanced its operational efficiency but also reinforced its commitment to quality, regulatory compliance, and environmental sustainability, positioning it for long-term growth, competitiveness, and leadership in the cosmetics manufacturing sector.

AUTHOR CONTRIBUTIONS

P.K. contributed to conceptualization, study design, methodology, data analysis and interpretation, and writing the original draft of the manuscript. F.W. contributed to supervision, project administration, correspondence, and review and editing of the manuscript. N.V., W.M., and S.C. contributed to methodology, interpretation of the findings, and critical revision of the manuscript. All authors discussed the results, contributed to the final version of the manuscript, and approved the submitted version.

REFERENCES

- Azamfirei, V., Psarommatis, F., & Lagrosen, Y. (2023). Application of automation for in-line quality inspection, a zero-defect manufacturing approach. *Journal of Manufacturing Systems*, 67, 1–22. <https://doi.org/10.1016/j.jmsy.2022.12.010>
- Carrim, M. O., & Gupta, K. (2024). Improving efficiency and productivity of a production line using lean manufacturing and DMAIC. *International Research Journal of Science, Technology, Education, and Management*, 4(3), 1–14. <https://doi.org/10.5281/zenodo.13858698>



- Chauhan, P., Modi, D., Seemababu, M., Giri, S., Rathod, A., Patel, K. K., & Patel, C. N. (2022). Review on analytical quality by design and PAT. *World Journal of Pharmaceutical Research*, 11(14), 244–266.
- Chiang, P.-C., Ma, H.-W., Wen, L., & Lin, C.-H. (2024). Reduction, reuse, recycling, recovery, redesign. In *Introduction to green science and technology for green economy: Principles and applications* (pp. 255–285). Springer. https://doi.org/10.1007/978-981-99-9676-6_11
- da Costa, T. P., Gillespie, J., Cama-Moncunill, X., Ward, S., Condell, J., Ramanathan, R., & Murphy, F. (2023). A systematic review of real-time monitoring technologies and its potential application to reduce food loss and waste: Key elements of food supply chains and IoT technologies. *Sustainability*, 15(1), Article 614. <https://doi.org/10.3390/su15010614>
- Dodou, K. (Ed.). (2022). *Current and evolving practices in the quality control of cosmetics*. MDPI. <https://www.mdpi.com/books/reprint/5777-current-and-evolving-practices-in-the-quality-control-of-cosmetics>
- Garcia, L. S. (2024). *Clinical laboratory management* (3rd ed.). Springer.
- Gilchrist, A. J. (2022). *Making quality cosmetics: Good manufacturing practice and ISO 22716: 2007*. Royal Society of Chemistry.
- Ho, Y.-S., Cavacece, Y., Tartaglione, A. M., & Douglas, A. (2023). Publication performance and trends in total quality management research: A bibliometric analysis. *Total Quality Management & Business Excellence*, 34(1–2), 97–130. <https://doi.org/10.1080/14783363.2022.2031962>
- Juran, J. M. (2012). *Quality planning and analysis: From product development through use* (5th ed.). McGraw-Hill.
- Kokkinou, A. (2023). How organizations can harness continuous improvement practices to develop their data analytic capability: A conceptual paper. In T. van Kollenburg, A. Kokkinou, & O. McDermott (Eds.), *Challenging the future with lean* (pp. 52–69). Springer. https://doi.org/10.1007/978-3-031-63265-5_5
- Mildau, G. (2018). General review of official methods of analysis of cosmetics. In A. Salvador & A. Chisvert (Eds.), *Analysis of cosmetic products* (2nd ed., pp. 67–83). Elsevier. <https://doi.org/10.1016/B978-0-444-63508-2.00004-7>
- Mishra, L., & Kurmi, B. D. (2023). Cosmetics regulations and standardization guidelines. *Pharmaspire*, 15, 137–150. <https://doi.org/10.56933/Pharmaspire.2023.15124>
- Pan, M., Zhang, G., Zhang, W., Zhang, J., Xu, Z., & Du, J. (2024). A review of intelligentization system and architecture for ultra-precision machining process. *Processes*, 12(12), Article 2754. <https://doi.org/10.3390/pr12122754>
- Redondo, G. L. M., Rojas, M. C., Salas, M. F. R., Corrales, D. G., Navarro, E. P., & Barquero, M. R. (2021). Characterization and comparison of quality management systems for cosmetic products in the world. *International Journal of Drug Regulatory Affairs*, 9(3), 47–56. <https://doi.org/10.22270/ijdra.v9i3.491>
- Rico, F., Mazabel, A., Egurrola, G., Pulido, J., Barrios, N., Marquez, R., & García, J. (2024). Meta-analysis and analytical methods in cosmetics formulation: A review. *Cosmetics*, 11(1), Article 1. <https://doi.org/10.3390/cosmetics11010001>
- Shastri, D. H., Gandhi, S., & Almeida, H. (2024). Enhancing collaboration and interdisciplinary strategies for navigating innovative technologies and regulatory approvals in the cosmetic industry. *Current Cosmetic Science*, 3(1), Article e26667797324383. <https://doi.org/10.2174/0126667797324383240913033156>
- Singh, C. D., & Kaur, H. (2021). *Sustainable green development and manufacturing performance through modern production techniques*. CRC Press.
- Yarosan, E. V., Chowdhury, S., Mangla, S. K., Dey, P., Chan, F. T. S., & Roux, M. (2024). A systematic literature review exploring and linking circular economy and sustainable development goals in the past three decades (1991–2022). *International Journal of Production Research*, 62(4), 1399–1433. <https://doi.org/10.1080/00207543.2023.2270586>
- Zangheri, M., Calabretta, M. M., Calabria, D., Fiori, J., Guardigli, M., Michelini, E., Melandri, S., Maris, A., Mirasoli, M., & Evangelisti, L. (2021). Immunological analytical techniques for cosmetics quality control and process monitoring. *Processes*, 9(11), Article 1982. <https://doi.org/10.3390/pr9111982>
- Zhou, R., Chen, Y., Zhang, J., & Guo, P. (2023). Research progress in liquid cooling technologies to enhance the thermal management of LIBs. *Materials Advances*, 4(18), 4011–4040. <https://doi.org/10.1039/D3MA00299C>