IJTMGH International Journal of Travel Medicine and Global Health

Int J Travel Med Glob Health. 2026 Jun;14(2):119-127 doi 10.30491/ijtmgh.2025.542532.1502
http://ijtmgh.com

Original Article Open Access

Single-Serve Instant Beverages and Traveler Health: Sachet-Filling Optimization for Safety and Quality

Sayyed Mohammadreza Sedehi*[1], Abdolah Alinejad[2], Narges Dehghanniri[3], Motahareh Sadat Dehghan Niri[4] , Niloofar Darroudi[4]

[1] School of Mechanical Engineering, College of Engineering, University of Tehran,Tehran, Iran.
[2] San Faravar Sepehr Manufacturing Group (Bargaz), Gonabad, Iran.
[3] Master of Health, Safety and Environmental Management (HSE), Environmental Health Expert, Yazd City Health Center, Health Assistant, Shahid Sadoughi University of Medical Sciences, Yazd.
[4] Faculty of Engineering, University of Gonabad, Gonabad.

***Corresponding Author:** Sayyed Mohammadreza Sedehi, School of Mechanical Engineering, College of Engineering, University of Tehran,Tehran, Iran. Email: mrsedehi@ut.ac.ir, Phone: +989180881303.

Received 2025-08-20; **Accepted** 2025-10-10; **Online Published** 2026-06-01

Abstract

This study presents a novel approach to enhancing traveler health and food safety by optimizing sachet-filling machine parameters for single-serve instant beverage packaging. Three main variables were investigated under controlled experiments: metallized film thickness (55, 75, and 95 µm), sealing temperature (125, 135, and 145 °C), and filling speed (slow, medium, and fast). Packaging performance was evaluated through three mechanical indicators package distortion, adhesion to the cutter, and seal integrity which are directly linked to hygienic and safety outcomes. Excessive distortion can compromise package stability and facilitate contamination, poor adhesion may lead to surface irregularities that harbor impurities, and weak seals increase the risk of microbial ingress and moisture penetration. Results indicated that increasing film thickness from 55 to 95 µm reduced cutter adhesion but caused higher distortion. Higher sealing temperatures (145 °C) improved adhesion, but combined with higher filling speeds, seal integrity deteriorated. Optimal conditions were identified at 75 µm film thickness, 135 °C sealing temperature, and medium filling speed. These settings minimized distortion and adhesion while ensuring strong sealing performance. The findings highlight how mechanical packaging characteristics act as proxies for safety assurance, offering a practical basis for industrial processes that reduce contamination risks and support consistent, hygienic single-serve packaging for travelers

Keywords: Packaging, Metallized film, Food materials, Instant beverage

Citation: Sedehi S-M, Alinejad A, Dehghanniri N, Dehghan Niri M-S , Darroudi N. Single-Serve Instant Beverages and Traveler Health: Sachet-Filling Optimization for Safety and Quality. Int J Travel Med Glob Health, 2026;14(2):119-127. Doi: 10.30491/ijtmgh.2025.542532.1502.

Introduction

In recent years, the consumption of instant beverages, particularly coffee-derived and blended products, has grown into one of the most dynamic sectors of the food and beverage industry. This growth is driven by their fast preparation, diverse flavors, and convenient portability [1-5]. Sachet packaging has emerged as a cost-effective and hygienic method for delivering such products. It plays a crucial role in maintaining product quality, shelf life, and consumer safety [6-9]. In addition to protecting against microbial contamination and moisture, this type of packaging prevents direct exposure of the product to environmental degradative agents. As a result, it preserves sensory quality and nutritional value until consumption [10]. Consequently, the choice of packaging materials and the optimization of the associated manufacturing process not only affect product quality but also influence production efficiency, final cost, and consumer satisfaction [11]. These factors highlight the importance of understanding both material properties and process parameters in achieving reliable packaging performance. Metallized films, typically composed of polymer and metal layers, have become one of the most widely used materials in packaging powdered and instant beverage products. Their popularity stems from superior barrier properties against moisture, oxygen, and light [12,13]. The thickness of these films is a critical parameter that governs mechanical and thermal performance. Variations in thickness directly impact package weight, flexibility, and barrier properties 14. Previous studies have shown that optimal thickness must balance sealing strength, processability, and material cost. Excessive thickness can increase energy demand and material costs during sealing, while insufficient thickness raises the risk of tearing or seal failure [15,16].

The heat-sealing process in sachet packaging is one of the most critical steps in production lines. It is also energy-intensive [17,18]. The energy and heat required for a strong seal depend on the thermodynamic properties and thickness of the film [19]. Industrial investigations indicate that increased film thickness generally requires higher temperatures and longer dwell times to ensure sufficient heat transfer to the inner layers. This may lower machine productivity and increase energy costs [20,21]. Conversely, thinner films reduce energy consumption due to lower heat requirements. However, they may compromise mechanical integrity of the seal, leading to leakage or seal failures during storage and distribution [22]. From an economic perspective, film thickness affects raw material costs and production efficiency. While thinner films reduce material usage and costs, they may increase the risk of product returns due to packaging failures [23]. Therefore, many recent studies have focused on identifying the optimal thickness that balances cost, quality, and productivity [24–26]. Despite extensive research, previous studies primarily focused on one or two parameters, such as seal integrity or energy consumption. Few works have addressed the combined effects of multiple machine parameters on comprehensive performance indicators. To fill this research gap, the present study introduces a novel approach by optimizing sachet-filling parameters to ensure traveler health and maintain the safety and quality of instant beverage products. Controlled experiments and multivariate correlation analysis were employed to evaluate the effect of film thickness on five key performance indicators: package weight, optimal sealing temperature, machine energy consumption, seal quality and strength, and ease of use. This integrated approach enables the identification of optimal conditions that not only ensure product safety and packaging quality but also provide practical guidance for industrial applications. The outcomes of this study can contribute to improved quality, reduced costs, enhanced energy efficiency, and the design of user-centered machinery.

Figure1. (a) Schematic illustrations of the sachet-filling process and (b) the equipment used .

Materials and Methods

For this study, metallized rolls of 55 µm (cream-colored) and 95 µm (purple-colored) thickness were utilized. Due to their multilayer metal–polymer structure with superior barrier properties, these films were considered suitable options for enhancing product shelf life and reducing the penetration of moisture and oxygen [27-30]. The instant coffee-mix powder was supplied by Bargaz Company, located in Gonabad, and was formulated with standardized proportions of instant coffee, sugar, and non-dairy creamer. Sachet samples were produced using a vertical form-fill-seal packaging machine manufactured in Iran. This machine is capable of precisely controlling key parameters, including metallized roll thickness, sealing temperature, filling speed, and sealing jaw pressure, thus allowing for controlled and repeatable experimental conditions. All tests were conducted in the industrial lines of Sun Faravar Sepehr Company using advanced quality control equipment to evaluate seal integrity and package consistency.

The optimization pathway consisted of several main stages. First, a set of designed experiments was implemented using the Taguchi method for three primary factors film thickness, sealing temperature, and filling speed in order to assess the main effects and interactions on performance indicators such as distortion, cutter adhesion, and seal quality. Data collected included sachet weight, sealing temperature, packaging quality, cycle time, machine energy consumption, and raw material costs. These datasets were subsequently analyzed using statistical methods, including Analysis of Variance (ANOVA) and main-effect as well as three-dimensional surface plots, to identify critical factors and optimal operating ranges for each response. Next, considering the multi-response nature of the study, a Desirability Function approach was employed to integrate the performance indices and determine optimal conditions. For responses where "smaller is better" (distortion and cutter adhesion), the desirability function was defined such that lower values received higher scores. Conversely, for responses where "larger is better" (seal quality), higher values corresponded to greater desirability. The overall desirability was computed using the geometric mean of individual responses, and optimization involved selecting the combination of film thickness, sealing temperature, and filling speed that maximized the overall desirability index. This methodology enabled the identification of operational conditions that simultaneously minimized cost, reduced distortion, and improved seal quality. The outcomes were validated against real production line data. Finally, the proposed optimization pathway from experimental design and data acquisition to statistical analysis and desirability function computation provides an evidence-based decision-making framework for the industrial production of instant beverage sachets. Moreover, it offers a comprehensive scientific and practical guideline for optimizing similar packaging processes within the broader food and beverage industry. The response variables (Distortion, Cutter Adhesion, and Seal Quality) were evaluated on a five-point ordinal scale, where 1 represents the lowest level (minimal distortion, weak adhesion, or poor sealing) and 5 represents the highest level (severe distortion, strong adhesion, or excellent sealing). This scoring system allowed the qualitative observations to be quantified for statistical analysis (Table 1).

Table 1. Experimental design

Sample	Thickness (μm)	Temperature (°C)	Filling Speed	Distortion	Cutter Adhesion	Seal Quality
1	55	125	Slow	2	5	4
2	55	135	Medium	3	4	4
3	55	145	Fast	1	3	2
4	75	125	Medium	3	4	4
5	75	135	Fast	2	3	3
6	75	145	Slow	4	3	3
7	95	125	Fast	4	2	3
8	95	135	Slow	5	2	2
9	95	145	Medium	4	2	2

Effect of Metallized Roll Thickness

The analysis of data and the plots presented in Fig.2 indicate that metallized film thickness plays a pivotal role in controlling package distortion. As shown in panel (a), reducing thickness from 95 to 55 µm led to a noticeable increase in distortion, since thinner films possess lower resistance to mechanical stresses during sealing and filling. However, panels (b) and (c) reveal that reduced thickness improved cutter adhesion and sealing quality. This effect arises from more uniform heat penetration and sealing pressure, which enhance bonding between layers. These results underscore the importance of selecting an optimal thickness in packaging design to simultaneously reduce waste and improve seal integrity.

Experimental data analysis confirmed that metallized roll thickness has a significant influence on package distortion. Decreasing thickness from 95 to 55 µm intensified the mechanical stresses within the film layers, resulting in greater deformation in the samples. This outcome highlights the geometric sensitivity of packaging to the mechanical resistance of the film [31]. On the other hand, thinner films had a remarkable positive effect on cutter adhesion and sealing quality. As illustrated in the three-dimensional surface plot **(**Fig.2-b**),** thinner films facilitated more uniform heat and pressure distribution, thereby improving interlayer bonding. This effect complements the distortion results, demonstrating that reduced thickness provides a qualitative advantage, although it may introduce geometric challenges in package shape [32]. The combined analysis suggests that the optimal film thickness should balance the trade-off between minimizing distortion and enhancing seal quality. The heatmap data **(**Fig.2-c**)** further confirm this balance by identifying critical regions where sealing performance and package geometry achieve optimal levels. From an industrial perspective, these findings emphasize the necessity of designing metallized films with appropriate thickness to achieve simultaneous improvements in package quality and geometric stability [33].

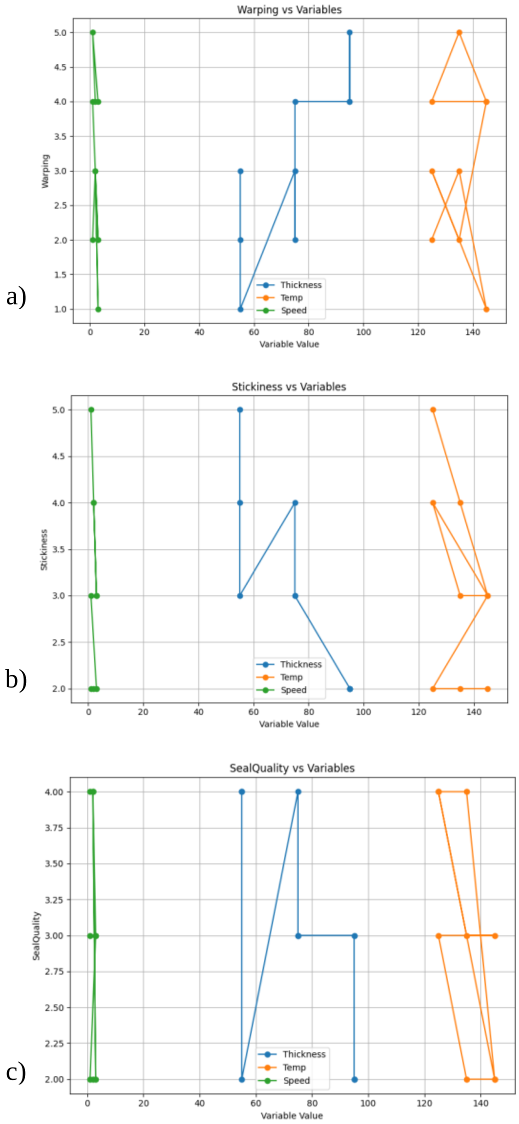

Figure 2. Linear interaction analysis results

Filling speed exhibits a nonlinear influence on the three evaluated responses. The line and scatter plots in Fig.3, where speed effects are represented by different colors, reveal that increasing speed from slow to medium enhances sealing quality (Fig.3-c) and reduces cutter adhesion (Fig. 3-b). This occurs because a more uniform material flow inside the sachet enables balanced pressure distribution at the sealing zone. However, at higher speeds, a significant increase in distortion (Fig.3-a) and deterioration in seal quality were observed, which can be attributed to the imbalance between the internal material pressure and the mechanical resistance of the film. These findings highlight the practical importance of optimizing filling speed in packaging industries to achieve high seal quality while minimizing distortion. This effect is accompanied by reduced local stresses and the prevention of unwanted wrinkling [34].

As the results indicate, when the filling speed is increased excessively, distortion and seal degradation rise dramatically. This phenomenon reflects the dynamic limitations of the packaging machine and the reduced heat-contact time on the film at higher operating speeds. A simultaneous analysis of distortion and seal quality suggests that the optimal speed range lies at medium levels. Overall, both experimental data and simulations demonstrate that filling speed must be adjusted to balance material pressure and heat transfer at the sealing interface. These insights hold direct applications for industrial production lines, where determining the appropriate speed not only improves product quality but also reduces the risk of defects and packaging failures [35-38].

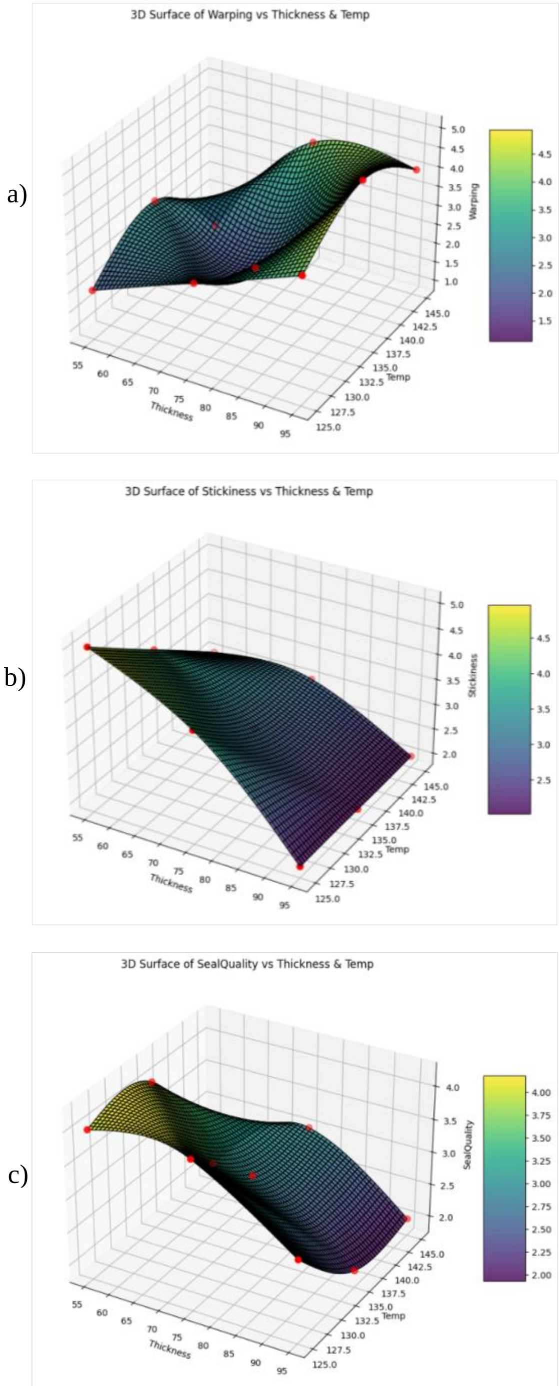

Figure 3. 3D interaction analysis results

Sealing temperature exerts a significant influence on seal quality and cutter adhesion, while its effect on package distortion is relatively limited. The three-dimensional surface plots in Fig.3 and the heatmaps in Fig.4 clearly illustrate the interaction of sealing temperature with film thickness and filling speed. An increase in temperature leads to higher cutter adhesion and reduced seal quality, as excessive heat may decrease the film's viscosity and hinder the formation of adequate mechanical bonding between layers [39]. These plots also highlight the critical regions where sealing performance deteriorates. From an industrial standpoint, precise control of sealing temperature is crucial for maintaining final product quality and minimizing production waste. The combined analysis of experimental data and 3D plots indicates that the optimal sealing temperature lies within a range that balances adhesion and seal quality. Scatter plot results further demonstrate that lower sealing temperatures, when combined with appropriate film thickness and filling speed, can yield minimal distortion and maximum seal integrity. These findings emphasize the importance of accurate sealing temperature control in industrial production. Based on this dataset, it is possible to define an operational temperature window that ensures geometric stability of the package, optimizes seal quality and cutter adhesion, and minimizes product waste [40,41].

The three-dimensional surface

plots and heatmaps (Fig.3 and 4) reveal the complex interactions among the factors. An appropriate combination of medium film thickness, medium filling speed, and lower sealing temperature resulted in minimal distortion and maximum seal quality. These findings confirm that multi-response optimization using the desirability function can provide a practical strategy for designing packaging processes with minimal waste and superior quality. Therefore, selecting optimal operational conditions not only enhances production line efficiency but also ensures that the final product meets industrial quality standards. The combination of medium thickness, medium speed, and lower temperature consistently achieved the lowest distortion and the highest sealing quality. Analysis through the multi-response desirability function demonstrated that optimal conditions can simultaneously improve product quality and reduce production costs [42-44]. Simulation results and experimental data were integrated to establish a practical decision-making framework for industrial production lines. Heatmap and surface plots identified critical and optimal regions, enabling prediction of product behavior under different operational scenarios. Ultimately, the proposed optimization pathway including experimental design, data collection, statistical analysis, three-dimensional simulation, and desirability function calculation provides a comprehensive framework for the industrial production of instant beverage sachets. After identifying the best and worst process conditions, visualizations corresponding to these states are presented to clearly illustrate performance variations across different parameter levels.

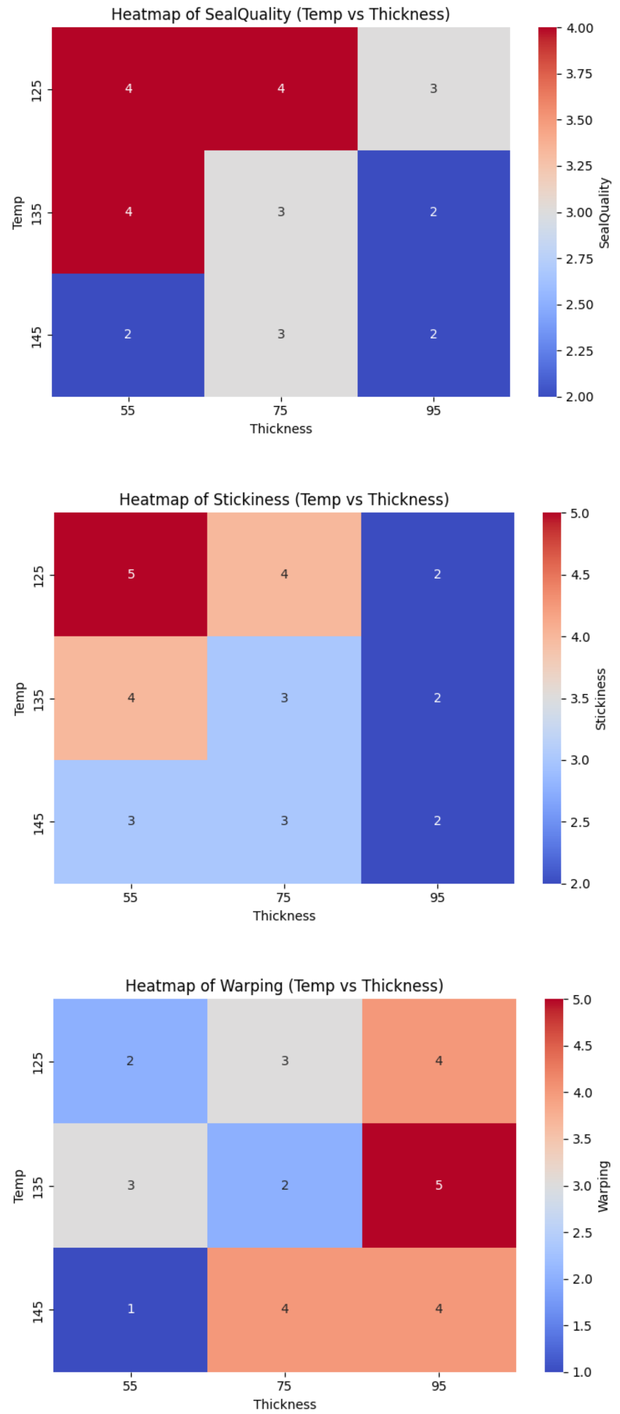

Figure 4. Heatmap interaction analysis results

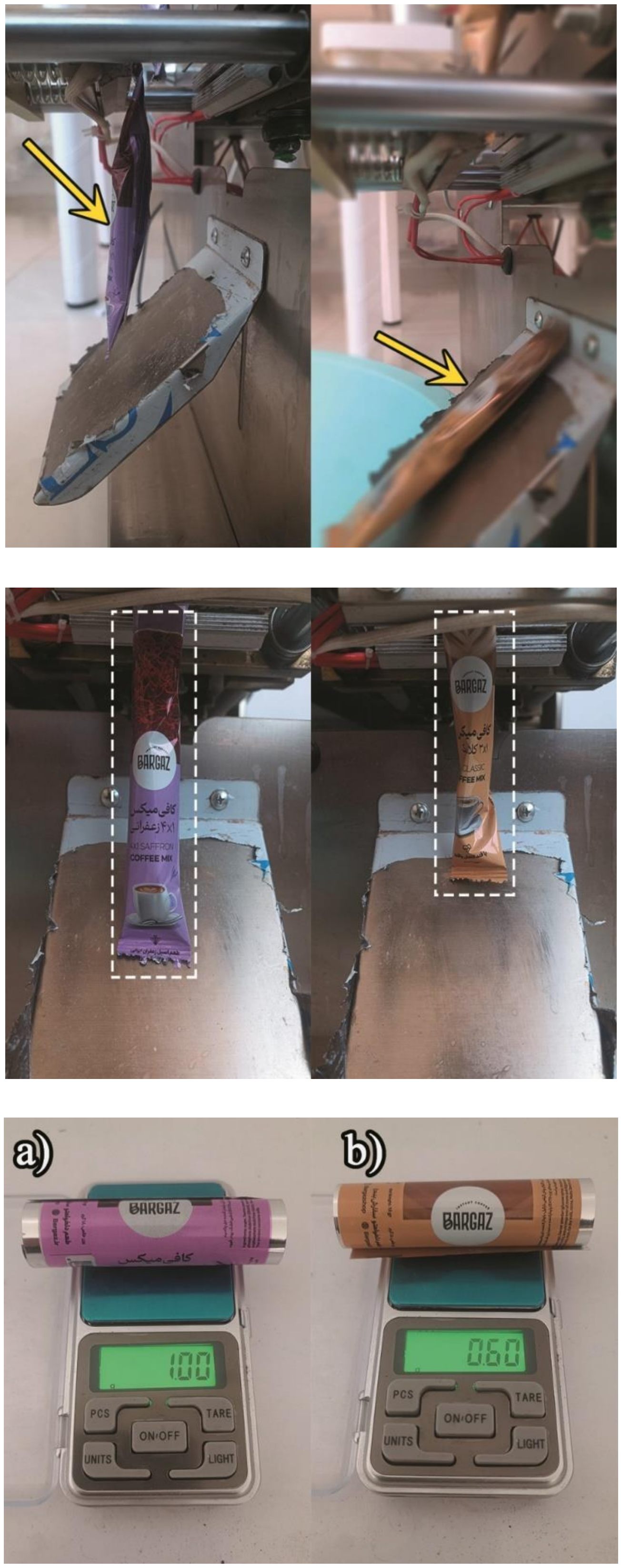

Figure 6. Overweight for thicknesses: a) 95 µm and b) 55 µm

Metallized film thickness not only affects the technical and economic aspects of the production process but also carries significant environmental implications. Increasing film thickness directly results in higher consumption of raw materials, greater energy demand during the sealing process, and ultimately a larger carbon footprint. Additionally, the increased weight of thicker packaging leads to higher fuel consumption during transportation and distribution, thereby exacerbating greenhouse gas emissions. Conversely, the use of thinner films (e.g., 55 µm) offers considerable economic and environmental advantages by reducing the consumption of natural resources and energy, although challenges such as increased distortion or a relative decline in seal quality may also arise. Therefore, selecting the optimal thickness must adopt a holistic approach that balances packaging quality and durability with minimized energy and material consumption. The development of advanced technologies that allow for reduced film thickness without compromising performance could steer the packaging industry toward sustainability and lower environmental impact [45-49]. Fig.7 illustrates a comparison of the performance of two metallized films with thicknesses of 55 and 95 µm across seven key indicators: weight, energy consumption, distortion, adhesion, operational speed, cost, and environmental compatibility.

The statistical analysis demonstrates that film thickness, sealing temperature, and filling speed all significantly affect the performance indicators of sachet packaging. As shown in the heatmap (Figure 3), film thickness has the strongest impact on distortion, with thinner films experiencing higher mechanical stress and consequently more deformation. Cutter adhesion is primarily influenced by sealing temperature, where higher temperatures improve layer bonding but can reduce seal quality when combined with higher filling speeds. Seal quality is most sensitive to filling speed, with medium speed offering the optimal balance between adhesion and integrity. The confidence intervals of the model coefficients indicate that the estimates are stable with 95% confidence, confirming that observed variations are due to actual factor effects rather than random sampling. This statistical evidence reinforces the qualitative trends observed in the line and surface plots and provides a robust foundation for process design decisions. By integrating ANOVA, heatmaps, and confidence intervals, engineers can identify critical factor levels and focus multi-response optimization on minimizing distortion, reducing cutter adhesion, and maximizing seal quality. This combined approach offers both a scientific and practical framework for process adjustments and ensures consistent, high-quality packaging performance in industrial production.

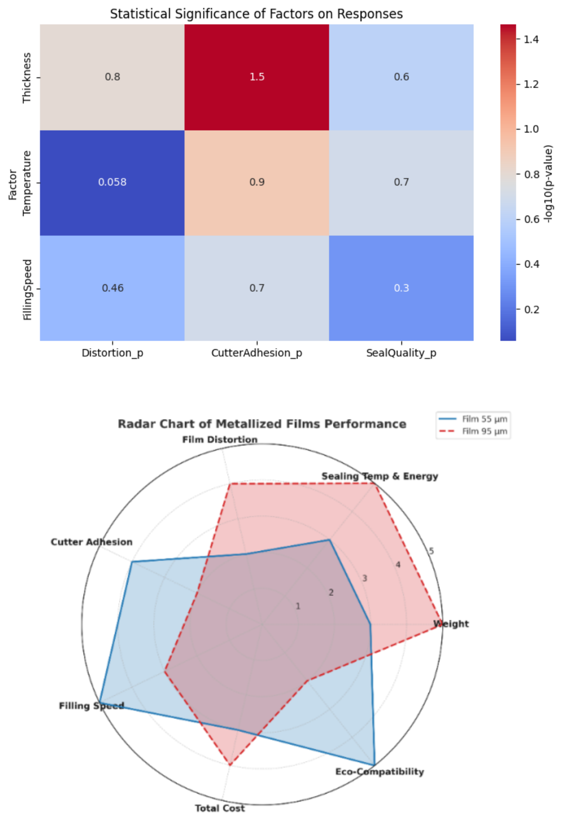

Figure 7. Chart of aggregated results for 95 and 55 µm thicknesses

Results

The findings of this study indicate that the three main process variables metallized film thickness, sealing temperature, and filling speed play a decisive role in both packaging quality and the safety of single-serve instant beverage sachets. Data analysis revealed that increasing the film thickness from 55 to 95 µm, while reducing adhesion to the cutter, led to higher package distortion and, under certain conditions, a decline in seal integrity. Higher sealing temperatures (145 °C) decreased adhesion; however, when combined with high filling speeds, seal quality deteriorated. In contrast, a medium sealing temperature (135 °C) combined with 55 µm film thickness and medium filling speed produced a balanced condition that maintained both seal quality and safe, reliable single-serve packaging.

The four key outcomes of this research are as follows:

1. **Film Thickness:** Increasing thickness from 55 to 95 µm reduced cutter adhesion but increased package distortion and negatively affected overall packaging reliability.
2. **Sealing Temperature:** Higher temperatures (145 °C) reduced adhesion, yet at high filling speeds, seal integrity and product safety decreased.
3. **Filling Speed:** Medium filling speed combined with medium temperature provided optimal sealing quality and product safety, whereas high speed led to reduced quality and higher risk of compromised packaging.
4. **Optimal Conditions:** The combination of 55 µm thickness, 135 °C sealing temperature, and medium filling speed was identified as optimal, controlling distortion, reducing adhesion, ensuring safe and reliable single-serve packaging, and maintaining high sealing quality.

Highlights

What Is Already Known?

Sachet-filling machine parameters (metallized film thickness, sealing temperature, and filling speed) play a crucial role in packaging quality and product safety, yet their combined effects have rarely been evaluated simultaneously. Previous studies have mainly focused on single variables, without providing a comprehensive optimization approach for ensuring traveler health and product safety.

What Does This Study Add?

This study identifies the optimal conditions (55 µm film thickness, 135 °C sealing temperature, and medium filling speed) that minimize package distortion and cutter adhesion while ensuring high-quality sealing and safe single-serve beverage packaging. Findings demonstrate that precise adjustment of combined parameters significantly enhances packaging reliability, reduces health risks, and safeguards traveler safety in instant beverage consumption. The study provides a reliable foundation for designing future industrial processes in single-serve packaging with a focus on safety, quality preservation, and consumer protection.

Authors' Contributions

All authors equally contributed to this study.

Acknowledgments

The authors would like to express their appreciation to Bargaz (https://bargaz.ir/-Iran, Gonabad) and Ms. Maryam Mohammadzadeh (Iran, Gonabad) for their constructive support, which has greatly benefited the authors.

Conflicts of Interest Disclosures

The authors declared no conflict of interest.

Consent For Publication

All authors expressed explicit consent for the publication of this manuscript.

Ethics approval

Written informed consent was obtained from the patient for the publication of the article and any associated images.

Funding/Support

The present study has no Funding resources.

The extent of AI use

None.

References

1. Dautkanova D, Kazhymurat A, Dautkanov N, Ussembayeva Z, Mussayeva S. Development of a functional instant drink using soy isolate and collagen hydrolysate. Caspian J Environ Sci. 2025 Jun 26;1–2.
2. Buda M. Consumers’ behavior towards instant coffee drinking in Malaysia. Malays J Agric Econ. 2025 Aug 1;32(1).
3. Park S, Hwang IS, Yoon G, Lim M, Park MK, Oh J, et al. Do you drink coffee, or brand? Brand effect on consumers' liking and emotional responses to instant coffee among Korean consumers. J Sens Stud. 2025 Feb;40(1)\:e70022. doi.org/10.1111/joss.70022
4. Wierzejska RE, Gielecińska I. Evaluation of the caffeine content in servings of popular coffees in terms of its safe intake can we drink 3–5 cups of coffee per day, as experts advise?. Nutrients. 2024 Jul 23;16(15):2385. doi.org/10.3390/nu16152385
5. Blazevska Z, Pavlova V. Application of different sweeteners in the production of instant drinks. J Hyg Eng Des. 2024 Apr 1;47.
6. Demircan B, Velioglu YS. Revolutionizing single-use food packaging: a comprehensive review of heat-sealable, water-soluble, and edible pouches, sachets, bags, or packets. Crit Rev Food Sci Nutr. 2025 Mar 18;65(8):1497–517. doi.org/10.1080/10408398.2023.2295433
7. Rupérez D, Nerín C, Silva F. Controlling beef microbial spoilage with diacetyl-based active packaging sachet. Food Res Int. 2025 May 1;209:116176. doi.org/10.1016/j.foodres.2025.116176
8. Kadirvel V, Palanisamy Y, Ganesan ND. Active packaging system—an overview of recent advances for enhanced food quality and safety. Packag Technol Sci. 2025 Feb;38(2):145–62.
9. Nurhadi RP, Chongcharoenyanon B, Boonsiriwit A, Bumbudsanpharoke N, Ko S. Exploring the feasibility of biodegradable films for antimicrobial absorbent sachets and CO2 emitters as sustainable active packaging. J Food Eng. 2025 Feb 1;386:112289. doi.org/10.1016/j.jfoodeng.2024.112289
10. Raajeswari P, Manivel D, Dhanapal TA, Menkinoska M, Pavlovska G, Helal M, et al. Sustainable biodegradable tapioca starch films enhanced with basil oil, carboxymethyl cellulose, and citric acid for functional food packaging applications. Front Sustain Food Syst. 2025 Jun 25;9:1610769. doi.org/10.3389/fsufs.2025.1610769
11. Ting L, Ahn J. How the environmental friendliness of food delivery packages shapes sustainable customer behavior. Soc Responsib J. 2025 Feb 5;21(4):809–25. doi.org/10.1108/srj-01-2024-0031
12. Marangoni Júnior L, Rodrigues RM, Pereira RN, Ito D, Teixeira FG, Padula M, et al. Impact of ohmic heating conditions on the behavior of metallized flexible packaging. J Food Meas Charact. 2025 Jul 11;1–0. doi.org/10.1007/s11694-025-03482-5 .
13. Leccese F, Pirondi A, Moroni F, Guadagno R, Rimediotti F, Sullo L. Mechanical characterization of innovative recyclable monomaterial films and laminates for food packaging. Proc Inst Mech Eng L J Mater Des Appl. 2025 Mar 3:14644207251324375. doi.org/10.1177/14644207251324375
14. Piergiovanni L, Limbo S. The protective effect of film metallization against oxidative deterioration and discoloration of sensitive foods. Packag Technol Sci. 2004 May;17(3):155–64. doi.org/10.1002/pts.651
15. Del Nobile MA, Mensitieri G, Aldi A, Nicolais L. The transport mechanisms of gases through metallized films intended for food packaging applications. Packag Technol Sci. 1999 Nov;12(6):261–9.
16. Niazmand R, Yeganehzad S, Niazmand A. Application of laminated and metallized films to prolong the shelf life of dried barberries. J Stored Prod Res. 2021 May 1;92:101809. doi.org/10.1016/j.jspr.2021.101809
17. Rajapakse UK, Samarasinghe TT, Kithmini S, Gayashi B, Jayarathna HU, Jayasinghe CV. Evolution of food packaging and its effect on human food. In: How technological advances change human food. 2025 Sep 17:261. doi.org/10.1201/9781003431107-15
18. Mkhari T, Adeyemi JO, Fawole OA. Recent advances in the fabrication of intelligent packaging for food preservation: a review. Processes. 2025 Feb 14;13(2):539. doi.org/10.3390/pr13020539
19. Ravi H, Manimehalai N, Roshan RU, Ramesh P, Selvam K. Design and performance optimization of a lab-scale pouch pasteurization system for crab meat using retort pouches: a predictive modelling study. Turk J Fish Aquat Sci. 2025 Mar 13;25(9). doi.org/10.4194/trjfas25035
20. Poddar D, Pandey K, Yoo HM. Streamlining electrospun shellac coatings on paper for high moisture strength and barrier food packaging film: tailoring the processing parameters for accelerated coating. Int J Biol Macromol. 2025 Mar 1;297:139855. doi.org/10.1016/j.ijbiomac.2025.139855
21. Gibney IV MJ. Predicting package defects: quantification of critical leak size \[dissertation]. Virginia Tech; Year not specified.
22. Ozguler A, Morris SA, O’Brien Jr WD. Ultrasonic imaging of micro-leaks and seal contamination in flexible food packages by the pulse-echo technique. J Food Sci. 1998 Jul;63(4):673–8. doi.org/10.1111/j.1365-2621.1998.tb15810.x
23. Zhou W, Hinz O, Benlian A. The impact of the package opening process on product returns. Bus Res. 2018 Sep;11(2):279–308. doi.org/10.1007/s40685-017-0055-x
24. Istiqomah A, Saputra OA, Firdaus M, Kusumaningsih T. Response surface methodology as an excellent tool for optimizing sustainable food packaging: a review. J Biosyst Eng. 2024 Dec;49(4):434–52. doi.org/10.1007/s42853-024-00243-y

25. Cooper MR, Douglas GL. Integration of product, package, process, and environment: a food system optimization. In: NASA Human Research Program (HRP) Investigators' Workshop. 2015 Jan 1. Report No.: JSC-CN-32066.

26. Obersteiner G, Cociancig M, Luck S, Mayerhofer J. Impact of optimized packaging on food waste prevention potential among consumers. Sustainability. 2021 Apr 9;13(8):4209. doi.org/10.3390/su13084209

27. Driscoll RH, Rahman MS. Types of packaging materials used for foods. In: Handbook of Food Preservation. 2nd ed. CRC Press; 2020 Jun 10. p. 905–22. doi.org/10.1201/9780429091483-59

28. Driscoll RH, Rahman MS. Types of packaging materials used for foods. In: Handbook of Food Preservation. CRC Press; 2007 Jul 16. p. 935–56. doi.org/10.1201/9781420017373-49

29. Jones CE. Packaging. In: Beckett's Industrial Chocolate Manufacture and Use. Wiley; 2017 May 10. p. 620–53. doi.org/10.1002/9781118923597.ch26

30. Saravacos G, Kostaropoulos AE. Food packaging equipment. In: Handbook of Food Processing Equipment. Cham: Springer International Publishing; 2016 Dec 30. p. 645–96. doi.org/10.1007/978-3-319-25020-5_13

31. Fadiji T, Coetzee CJ, Berry TM, Opara UL. Investigating the role of geometrical configurations of ventilated fresh produce packaging to improve the mechanical strength–experimental and numerical approaches. Food Packag Shelf Life. 2019 Jun 1;20:100312. doi.org/10.1016/j.fpsl.2019.100312

32. Siracusa V, Ingrao C. Correlation amongst gas barrier behaviour, temperature and thickness in BOPP films for food packaging usage: a lab-scale testing experience. Polym Test. 2017 May 1;59:277–89. doi.org/10.1016/j.polymertesting.2017.02.011

33. Fadeyibi A, Akanbi OP, Kayode AT. Enhancing beef texture: optimizing the impact of non-ionizing radiation intensity, exposure time, and thickness of nanocomposite packaging. Food Bioproc Tech. 2025 Jan;18(1):942–52. doi.org/10.1007/s11947-024-03515-9

34. Wang HK, Lin YC, Chen TY, Wang CC, Hung CP. Optimizing warpage in semiconductor packaging using GA-NN and conditional GAN with explainable AI. Comput Ind Eng. 2025 May 19;111246.

35. Kumar P, Kishore A, Tripathi S, Lavanya, Chaudhary V, Gaikwad KK. Innovative strategies to improve the properties of paper with bio-sourced material and its application in food packaging: a review. Biomass Convers Biorefin. 2025 May;15(9):13037–53.

36. Udkar S. Emerging advanced packaging technologies and their impact on modern computer architecture. Int J Emerg Trends Comput Sci Inf Technol. 2025 Mar 5;6(1):56–63. doi.org/10.63282/3050-9246.ijetcsit-v6i1p107

37. Upadhyaya M, Sitaraman S, Ravva C, Zhang W, Tremble E, Vohra A, et al. High-speed packages for the chiplet era. In: 2025 IEEE 75th Electronic Components and Technology Conference (ECTC). 2025 May 27. p. 166–70. IEEE. doi.org/10.1109/ectc51687.2025.00035

38. Wu Y, Liang C, Yu F. Timing analysis and methods to improve the speed of the packaging machine. Food Mach. 2016;32(10):86–8. doi.org/10.1016/j.fpsl.2016.10.005

39. Bull MK, Steele RJ, Kelly M, Olivier SA, Chapman B. Packaging under pressure: effects of high pressure, high temperature processing on the barrier properties of commonly available packaging materials. Innov Food Sci Emerg Technol. 2010 Oct 1;11(4):533–7. doi.org/10.1016/j.ifset.2010.05.002

40. Mrkić S, Galić K, Ivanković M. Effect of temperature and mechanical stress on barrier properties of polymeric films used for food packaging. J Plast Film Sheeting. 2007 Jul;23(3):239–56. doi.org/10.1177/8756087907086102

41. Singh S, Gaikwad KK, Lee M, Lee YS. Temperature-regulating materials for advanced food packaging applications: a review. J Food Meas Charact. 2018 Mar;12(1):588–601. doi.org/10.1007/s11694-017-9672-5

42. Yakoubi S. Sustainable revolution: AI-driven enhancements for composite polymer processing and optimization in intelligent food packaging. Food Bioproc Tech. 2025 Jan;18(1):82–107. doi.org/10.1007/s11947-024-03449-2

43. Alper MM, Sezen B, Balcıoğlu YS. Machine learning applications in packaging industry optimization: a systematic literature review and future research directions. In: International Newyork Congress Conference. Baku, Azerbaijan: BZT Turan Publishing House; 2025. doi.org/10.5510/ogp20250101041

44. Liu Y, Guo L, Hu X, Zhou M. Sensor-integrated inverse design of sustainable food packaging materials via generative adversarial networks. Sensors. 2025 May 25;25(11):3320. doi.org/10.3390/s25113320

45. Faiz MR, Ismail H, Wibowotomo B, Sujito S, Kurniawan R, Falah MZ, et al. Optimizing instant herbal drink production with IoT-based sachet forming machines to increase productivity and quality. Bull Community Engagem. 2023 Nov 2;3(2):109–18. doi.org/10.51278/bce.v3i2.886

46. Daramola OM, Apeh CE, Basiru JO, Onukwulu EC, Paul PO. Sustainable packaging operations: balancing cost, functionality, and environmental concerns. Int J Soc Sci Except Res. 2025 Jan;4(1):79–97. doi.org/10.54660/ijsser.2025.4.1.79-97

47. Sabet M. Exploring biodegradable polymer composites for sustainable packaging: a review on properties, manufacturing techniques, and environmental impacts. Iran Polym J. 2025 Jan;34(1):123–42.

48. Kositcharoenkul P, Prempreeda A, Oo PZ, Deuja A, Vassanadumrongdee S, Gheewala SH, et al. Life cycle assessment of beverage packaging in Thailand: implications from modeling choices and alternative improvement policies. Resour Conserv Recycl. 2025 Mar 1;214:108022. doi.org/10.1016/j.resconrec.2024.108022

49. Du L, Huang X, Li Z, Qin Z, Zhang N, Zhai X, et al. Application of smart packaging in fruit and vegetable preservation: a review. Foods. 2025 Jan 29;14(3):447. doi.org/10.3390/foods14030447 .