

Technical sciences

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THERMAL STABILITY OF WEDDING CAKES DURING TRANSPORTATION AND OUTDOOR DISPLAY: A REVIEW OF ENVIRONMENTAL FACTORS, STRUCTURAL RISKS, AND ENGINEERING APPROACHES

Summary. *The increasing complexity of modern wedding cake designs has transformed pastry production into a multidisciplinary field combining culinary arts, food science, structural engineering, and logistics management. Contemporary wedding cakes frequently incorporate multiple tiers, suspended elements, edible sculptures, and temperature-sensitive fillings, making them highly vulnerable to environmental conditions during transportation and display. Outdoor wedding events present additional challenges due to elevated temperatures, solar radiation, humidity fluctuations, and limited access to refrigeration.*

This review examines the factors affecting the thermal stability of wedding cakes during transportation and outdoor display. Particular attention is given to the thermal behavior of ganache and buttercream finishing systems, the influence of environmental conditions on structural integrity, and the role of transportation-induced mechanical stresses. Published literature from food engineering, confectionery science, thermal processing, and food preservation was analyzed to identify critical variables associated with cake stability. In addition, engineering approaches commonly used in professional cake production were evaluated as methods for reducing structural and thermal risks.

The analysis indicates that environmental temperature, direct solar exposure, relative humidity, and transportation duration are the principal factors influencing cake performance. Chocolate ganache coatings demonstrate superior thermal stability compared with buttercream systems due to the crystalline structure of cocoa butter and reduced susceptibility to deformation at elevated temperatures [3; 14]. Furthermore, the integration of engineering principles, including load distribution systems, thermal insulation, and transportation planning, significantly improves the reliability of large-scale wedding cake installations.

The findings highlight the importance of adopting interdisciplinary approaches in modern cake architecture and provide practical recommendations for pastry professionals involved in the production and delivery of premium wedding cakes.

Key words: *wedding cake engineering, thermal stability, ganache, buttercream, transportation logistics, food safety, outdoor events, structural integrity, confectionery science.*

Introduction. The wedding cake has long been regarded as a symbolic centerpiece of wedding celebrations. However, over the last two decades, consumer expectations have evolved significantly, resulting in increasingly sophisticated cake designs characterized by greater height, structural complexity, and artistic detail. Modern wedding cakes frequently incorporate multiple tiers, suspended elements, edible sculptures, and architectural features that require advanced technical expertise beyond traditional pastry preparation.

Simultaneously, the growing popularity of outdoor weddings has introduced new environmental challenges affecting cake performance. Wedding cakes are commonly transported from production facilities to event venues, assembled on-site, and displayed for several hours before serving. During this process, cakes may be exposed to elevated temperatures, direct solar radiation,

fluctuations in relative humidity, and transportation-induced vibrations. These environmental stressors may compromise structural integrity, alter aesthetic appearance, and create food safety concerns [18].

Temperature is widely recognized as one of the most significant factors influencing the quality and stability of food products. According to Rahman [17], temperature directly affects moisture migration, fat crystallization, microbial growth, and physicochemical stability in complex food systems. In confectionery products, elevated temperatures accelerate softening processes in fat-based coatings and fillings, increasing the likelihood of structural deformation. These effects become particularly important in wedding cakes because decorative elements and multi-tier structures often depend on maintaining precise mechanical stability throughout transportation and display [9].

The selection of exterior finishing materials also plays a critical role in determining thermal performance. Professional cake decorators frequently utilize either buttercream or chocolate ganache as exterior coatings. While both materials provide aesthetic and functional benefits, their thermal properties differ substantially. Research on chocolate-based confectionery systems demonstrates that cocoa butter crystallization contributes to enhanced structural rigidity and improved resistance to thermal fluctuations [4]. By contrast, buttercream systems exhibit lower resistance to elevated temperatures due to the thermal behavior of milk fats and the incorporation of air during mixing [1].

Despite the practical importance of wedding cake transportation and display, limited academic literature specifically addresses thermal stability in large-scale celebration cakes. Most available research focuses on confectionery shelf life, chocolate science, food preservation, and food engineering applications. Consequently, there is a need to synthesize existing knowledge from these related disciplines and apply it to wedding cake production.

The purpose of this review is to examine the environmental, structural, and thermal factors affecting wedding cake stability during transportation and outdoor display. Specifically, this study aims to:

1. Identify the principal environmental variables influencing cake performance.
2. Compare the thermal characteristics of ganache and buttercream finishing systems.
3. Evaluate transportation-related structural risks.
4. Examine engineering approaches used to improve thermal stability and reliability.
5. Develop practical recommendations for professional pastry chefs and cake designers.

Literature Review

Thermal Stability of Confectionery Products

Thermal stability refers to the ability of a food product to maintain its physical, chemical, microbiological, and sensory characteristics under varying temperature conditions [17]. In confectionery products, thermal stability is strongly influenced by fat composition, water activity, moisture migration, and crystallization behavior [9].

Chocolate-based products have received particular attention due to the complex polymorphic properties of cocoa butter. Beckett [3] reported that stable crystal forms within cocoa butter contribute significantly to the mechanical strength and temperature resistance of chocolate products. Similar findings were reported by Lapčíková et al. [14], who demonstrated that properly formulated ganache systems maintain structural integrity more effectively than many alternative confectionery coatings.

The relationship between temperature and structural stability becomes increasingly important in products incorporating multiple components with different thermal properties. Moisture migration between fillings, sponge layers,

coatings, and decorative elements may accelerate quality deterioration when products are exposed to fluctuating environmental conditions [12].

Heat Transfer in Food Systems

Heat transfer mechanisms play a fundamental role in determining product stability during storage and transportation. According to Singh and Heldman [18], heat exchange in food products occurs through conduction, convection, and radiation.

Conduction involves heat transfer through direct contact between materials, while convection occurs through the movement of air surrounding the product. Radiation, particularly solar radiation, can significantly increase surface temperatures beyond ambient environmental conditions. These mechanisms frequently operate simultaneously during outdoor food display.

Food engineering studies have demonstrated that large products with greater thermal mass generally experience slower temperature fluctuations than smaller products [6]). However, uneven heat distribution may create localized regions of elevated temperature, increasing the risk of structural failure in sensitive components.

Structural Properties of Ganache and Buttercream

The thermal performance of cake finishing systems is closely related to their composition. Ganache typically consists of chocolate and cream, producing a semi-solid matrix stabilized by cocoa butter crystals. Buttercream systems consist primarily of butter, sugar, and aerated components.

Research on chocolate systems indicates that cocoa butter crystal networks contribute to improved structural rigidity and resistance to deformation [4]. In contrast, butter-based systems begin softening at relatively low temperatures due to the melting behavior of milk fats [1].

These differences suggest that ganache may provide superior performance in outdoor environments, particularly when cakes are exposed to elevated temperatures for prolonged periods.

Materials and Methods

Research Design

This study employed a narrative literature review methodology to examine the thermal stability of wedding cakes during transportation and outdoor display. A review approach was selected because direct experimental studies specifically investigating wedding cake stability remain limited in scientific literature. Consequently, relevant findings from food engineering, confectionery science, chocolate technology, food preservation, and transportation of temperature-sensitive food products were synthesized and evaluated.

The review focused on identifying environmental, structural, and material-related factors that influence the performance of multi-tier wedding cakes under real-world operating conditions.

Literature Selection Criteria

Scientific publications were selected according to the following criteria: publication between 2000 and 2024; relevance to food engineering or confectionery science; focus on thermal stability, food preservation, chocolate systems, or transportation logistics; availability through peer-reviewed journals, academic publishers, and government food safety agencies. Sources included: Foods; Comprehensive Reviews in Food Science and Food Safety; Food Processing Technology; Introduction to Food Engineering; FDA Food Code; Institute of Food Technologists publications. A total of twenty primary sources were included in the final analysis.

Variables Examined

The review examined five principal variables associated with wedding cake stability: Ambient temperature. Solar radiation exposure. Relative humidity. Transportation duration. Type of exterior coating. Particular emphasis was placed on comparing ganache-coated and buttercream-coated cakes due to their widespread use in professional wedding cake production.

Analytical Framework

The study evaluated environmental influences according to three categories:

Thermal Factors: ambient temperature; radiant heat; refrigeration interruptions. **Structural Factors:** cake height; tier count; support systems; transportation vibration. **Food Safety Factors:** dairy-based fillings; moisture migration; microbial growth risks. The collected findings were subsequently synthesized into comparative models and risk matrices.

Results and Discussion

Effect of Ambient Temperature on Cake Stability

The literature consistently identifies temperature as the most influential environmental factor affecting confectionery stability [17; 18]. Elevated temperatures accelerate fat softening, increase moisture migration, and reduce structural rigidity.

Wedding cakes are commonly assembled and stored between 2°C and 6°C prior to delivery. Outdoor wedding environments frequently expose cakes to temperatures exceeding 25°C, creating substantial thermal gradients that alter material properties.

Research indicates that butter-based systems begin to soften significantly above 20–22°C, while chocolate-based systems generally maintain acceptable rigidity until approximately 24–26°C [1; 4].

Table 1

Recommended Environmental Conditions for Wedding Cake Display

Variable	Recommended Range
Ambient Temperature	18–22°C
Relative Humidity	50–65%
Direct Sunlight Exposure	Avoided
Wind Exposure	Minimal
Refrigeration Availability	Preferred

The findings suggest that maintaining temperatures below 22°C substantially improves both structural reliability and food safety outcomes.

Influence of Solar Radiation

Solar radiation represents a unique challenge because surface temperatures may exceed ambient temperatures by a considerable margin. According to Fellows [6], radiative heat transfer can substantially accelerate warming in exposed food products.

Field observations reported in outdoor catering literature indicate that cake surfaces exposed to direct sunlight may become 8–15°C warmer than surrounding air temperatures [11].

Table 2

Estimated Surface Temperatures During Outdoor Display

Ambient Temperature	Surface Temperature in Sunlight
20°C	25–30°C
25°C	32–37°C
30°C	38–45°C
35°C	43–50°C

At these temperatures, buttercream-based systems frequently experience softening, while chocolate decorations may lose dimensional stability [4].

Consequently, shaded display locations should be considered a critical risk mitigation strategy for outdoor wedding events.

Influence of Relative Humidity

Humidity affects wedding cakes through moisture exchange processes. Water activity and moisture migration are recognized as key factors influencing confectionery quality and shelf life [2].

Excessive humidity may cause: fondant sweating; sugar bloom; collapse of wafer-paper decorations; deterioration of sugar flowers.

Table 3

Humidity Effects on Cake Components

Relative Humidity	Expected Impact
Below 50%	Minimal impact
50–65%	Optimal conditions
65–75%	Increased decoration risk
Above 75%	Significant deformation risk

These findings are consistent with observations reported in confectionery shelf-life studies.

Comparative Analysis of Ganache and Buttercream

One of the most important findings of this review concerns the comparative thermal behavior of ganache and buttercream coatings.

Ganache exhibits greater thermal resistance due to the crystalline properties of cocoa butter [3]. Buttercream, by contrast, contains milk fat and aerated structures that become unstable at lower temperatures.

Table 4

Thermal Characteristics of Common Cake Finishes

Property	Ganache	Buttercream
Structural Rigidity	High	Moderate
Heat Resistance	High	Moderate
Moisture Resistance	High	Moderate
Transportation Stability	High	Moderate
Outdoor Performance	High	Low–Moderate

The literature strongly supports the use of ganache-coated cakes for large-scale wedding installations and outdoor events [14].

Transportation-Induced Mechanical Stress

Transportation introduces additional challenges that are largely independent of thermal effects.

Mechanical forces generated during transportation include: acceleration; braking; cornering; vibration; road impact.

These forces become increasingly significant as cake height increases.

Table 5

Transportation Risk Factors

Risk Factor	Relative Impact
Road vibration	High
Transportation distance	High
Elevated temperature	High
Multi-tier construction On-site assembly	Very High
On-site assembly	Moderate

According to food logistics studies, transportation vibrations may contribute to cumulative structural fatigue in layered products [18].

Predictive Thermal Model

The thermal behavior of cakes during transportation may be approximated using Newton's Law of Cooling: $T(t) = T_{env} + (T_0 - T_{env}) e^{-kt}$

Where:

$T(t)$ = cake temperature at time t

T_{env} = ambient temperature

T_0 = initial temperature

k = heat transfer coefficient

t = time

This model predicts that cakes gradually approach environmental temperature during transportation and display.

Larger cakes generally exhibit slower warming rates because of increased thermal mass [6].

Risk Assessment Framework

Based on the reviewed literature, a simplified risk assessment model was developed: $R=T \times H \times S \times D$

Where:

R = overall risk index

T = temperature factor

H = humidity factor

S = solar exposure factor

D = display duration factor

Table 6

Risk Classification Matrix

Risk Index	Classification
<10	Low
10–20	Moderate
20–40	High
>40	Critical

This model provides a practical framework for evaluating wedding cake exposure conditions and identifying situations requiring additional protective measures.

The results collectively demonstrate that environmental management, material selection, and engineering design significantly influence wedding cake performance during transportation and outdoor display.

Conclusions. The findings of this review demonstrate that thermal stability is a critical determinant of wedding cake performance during transportation and outdoor display. Modern wedding cakes represent complex composite systems consisting of sponge layers, fillings, coatings, decorative elements, and structural supports, each responding differently to environmental stressors. Consequently,

successful cake delivery and presentation require a multidisciplinary understanding of food science, engineering principles, and logistical planning.

The analysis identified ambient temperature, solar radiation, relative humidity, transportation duration, and coating composition as the primary factors affecting wedding cake stability. Among these variables, temperature and direct sunlight exposure appear to have the greatest impact on structural performance. Elevated temperatures accelerate fat softening, moisture migration, and material deformation, while solar radiation may increase surface temperatures significantly above ambient environmental conditions. These findings are consistent with established principles of food engineering and thermal transfer described in previous studies [18].

A comparative review of commonly used exterior finishing systems indicates that chocolate ganache provides superior thermal resistance compared with buttercream-based coatings. The crystalline structure of cocoa butter contributes to enhanced rigidity, improved load-bearing capacity, and greater resistance to deformation under elevated temperatures [3; 14]. These properties make ganache particularly suitable for large-scale wedding cakes, extended transportation routes, and outdoor events where environmental control may be limited.

Transportation-related mechanical stresses were identified as an additional source of risk. Vibrations, acceleration forces, and repeated handling may compromise structural integrity, particularly in multi-tier cakes with elevated centers of gravity. The findings suggest that transportation planning should be considered an integral component of cake design rather than a separate operational process. The implementation of reinforced support systems, insulated transportation containers, and controlled environmental conditions can significantly reduce the probability of structural failure.

The proposed risk assessment framework demonstrates how environmental and operational variables may be integrated into a practical decision-making

model for professional pastry chefs and event planners. Although simplified, the model provides a foundation for evaluating exposure conditions and identifying situations that require additional protective measures. Future research may expand this framework through experimental validation and quantitative modeling of thermal behavior in complex confectionery structures.

In conclusion, the increasing popularity of outdoor weddings and architecturally complex cake designs has elevated the importance of thermal stability as a professional competency within contemporary pastry arts. The integration of food science, engineering design, and risk management principles can substantially improve the reliability, safety, and aesthetic performance of wedding cakes under challenging environmental conditions. Continued research in this area may contribute to the development of advanced materials, predictive monitoring systems, and innovative structural solutions capable of supporting the next generation of cake architecture.

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