An Innovative Approach in Gastronomy: Ultrasound Technology

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Abstract

Ultrasound, which uses high-frequency sound waves, induces significant physical and chemical changes in food products, making it a valuable tool for various applications. It enhances food safety, quality, and preparation efficiency by improving mass transfer, disrupting cellular structures, and accelerating chemical reactions. This review aims to explore the integration of ultrasound technology into gastronomy, emphasizing its potential impact on modern culinary practices. Firstly, ultrasound effectively reduces microbial loads and chemical residues on food surfaces, enhancing food safety. Secondly, in food processing applications, ultrasound accelerates marination processes and improves meat tenderness, with ultrasonic cutting providing precision in processing foods. Thirdly, ultrasound improves the stability of emulsions and the consistency of homogenized products. This technology's ability to create stable foams, accelerate gel formation, and extract aromatic compounds paves the way for new gastronomic discoveries. Additionally, in the realm of diagnostic and quality control, ultrasound enables rapid and non-invasive quality assessments. The primary focus areas of this review include the applications of ultrasound in decontamination, marination, tenderization, cutting, diagnostic analysis, homogenization, emulsification, dehydration, rehydration, and molecular gastronomy. This study demonstrates that ultrasound technology not only enhances the sensory and aesthetic qualities of food but also supports innovative culinary techniques in molecular gastronomy. Based on a comprehensive literature search and professional experiences, this review concludes that the integration of ultrasound in gastronomy has the potential to significantly enhance food preparation methods, contributing to more efficient, creative, and high-quality culinary experiences.

Keywords: Gastronomy, Ultrasound, Culinary, Innovative Approach.

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1. Introduction

Gastronomy, a field that has gained significant popularity in recent years, is characterized by a continuous pursuit of innovation and excellence. Chefs and culinary scientists continuously seek new ways to enhance flavor, texture, and overall dining experiences, making the integration of advanced technologies increasingly significant. Food science and technology developments directly impact gastronomic practices, contributing to greater diversity in culinary applications.

Over the past quarter-century, ultrasound technology has been the subject of numerous studies in food science and technology, contributing to many innovations and becoming increasingly integrated into production processes.

Ultrasound technology employs high-frequency sound waves to induce physical and chemical changes in food products. These sound waves create microscopic cavitation bubbles in liquids, which implode and generate intense localized energy. This process can improve mass transfer, disrupt cellular structures, and accelerate various reactions within food matrices. These capabilities make ultrasound a valuable tool for various culinary applications, including the enhancement of traditional cooking methods and the development of new gastronomic techniques.

In preparing this review study, relevant scientific resources were reviewed using a comprehensive strategy. This review aims to provide an extensive and

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objective evaluation of the integration of ultrasound technology into gastronomy based on a thorough literature search and professional experiences. By examining its scientific principles, practical applications, and benefits, this review aims to demonstrate the potential of ultrasound technology to enhance both the sensory and aesthetic qualities of food. This review also explores the integration of ultrasound technology into gastronomy, highlighting its potential for various culinary applications.

2. Ultrasound Technology

Ultrasound refers to sound waves with frequencies above 20 kHz, which are too high to be detected by the human ear. In other words, ultrasound is mechanical energy consisting of 20,000 or more sound waves per second (Mason et al., 2005). The fundamental factor responsible for the effects of ultrasonic processes in food processing is acoustic cavitation. Sequential compression and rarefaction events occur when a sound wave passes through a liquid. During the rarefaction phase, if the negative pressure exceeds the tensile strength of the liquid, microbubbles and cavities form.

These bubbles, created using high-power ultrasound, rapidly grow and collapse after a few oscillations, a phenomenon known as cavitation (Feng and Yang, 2011). Cavitation derives its effect from the concentration of acoustic energy in small volumes, resulting in extremely high localized temperatures (approximately 2000-5000°C), very high pressures (approximately 10-100 MPa), micro shock waves, and the emission of light energy, according to the hot-spot theory.

There are two types of cavitation: stable cavitation and transient cavitation. Stable cavitation occurs at relatively low ultrasonic intensities of 1-3 W/cm² and typically contains gas and vapor. It does not play a significant role in chemical effects. If the nonlinear oscillations of bubbles begin to grow due to acoustic and environmental factors, the bubbles may transition to transient cavitation and collapse violently. However, the intensity of these collapses is lower than that of normal transient cavitation (Santos et al., 2009; Weiss et al., 2011). Stable cavitation is generally required for processes, such as emulsification, microbial, and enzymatic deactivation. In contrast, processes like dehydration, rehydration, and degassing prefer transient cavitation. Diagnostic ultrasonic processes utilize high frequencies and low energy to avoid cavitation formation.

3. Applications of Ultrasound Technology in Gastronomy

3.1. Decontamination

Decontamination is the process of removing or inactivating harmful microorganisms, chemical contaminants, or physical contaminants from food surfaces. Microbial contamination in foods is a significant issue in food production facilities because it may lead to foodborne illnesses and severe health risks. Although chemical contamination typically does not cause acute problems, it remains a significant public health concern. Therefore, the inactivation or removal of harmful microorganisms, especially pathogens, and the elimination of physical contaminants and various chemical residues like pesticides are crucial aspects of food production (Jay, 2000).

In culinary applications, decontamination is a necessary process for ensuring food safety, reducing economic losses, and maintaining quality standards. Significant cross-contamination risks exist, especially with fresh vegetables, meat, seafood, and eggs. Ensuring the safety of these products using simple and effective methods without compromising their quality is essential. Therefore, developing new food processing techniques for culinary applications is required.

Research conducted by Kılıçlı et al. (2019) and Ertugay & Başlar (2010) has shown that ultrasound can be utilized for microbial decontamination, including the inactivation of pathogenic microorganisms. Additionally, ultrasound technology can be an effective tool for removing physical contaminants and decontaminating pesticides (Cengiz et al., 2018), either alone or in combination with various techniques. Ultrasound technology can also be used for the physical cleaning of various kitchen equipment and ensuring microbial safety.

3.2. Marination

Marination is the process of enhancing the flavor, aroma, and texture of food items, especially meats and vegetables, by soaking them in various liquid mixtures (marinades) for a specified period. This process not only imparts flavor to the food but also improves its textural quality. It is employed for multiple purposes, such as enhancing the flavor and tenderness of meats, poultry, fish, and other seafood, as well as improving the taste and making vegetables more aromatic before cooking (Raj et al., 2023).

Ultrasound technology utilizes high-frequency sound waves to allow the marinade to penetrate food more quickly and deeply. Using ultrasound technology in marination offers several advantages, including the reduction of marination time, improved flavor and aroma penetration, enhanced microbial safety, and time savings. Studies by González-González et al. (2017) and Çimen et al. (2024) have shown that ultrasonic marination of meats can be an effective alternative to conventional methods.

3.3. Tenderization

Tenderization is the process of softening meat and enhancing its eating quality, making it more tender. This procedure is significant in gastronomy and culinary practices to facilitate easier chewing and digestion of meat. Conventionally, meat tenderization is achieved using mechanical, enzymatic, chemical, or thermal methods.

Ultrasound, a non-thermal process, has the potential to be effectively utilized in meat tenderization within culinary applications. Applying ultrasound to meat induces various physical and chemical changes, thereby softening its texture and improving its eating quality. Ultrasonic tenderization works by breaking down the myofibrillar proteins that bind pieces of meat together, resulting in a more tender texture (McClements, 1996). This technique is often combined with marination, allowing the marinade to penetrate the meat while simultaneously breaking down connective tissues to soften the meat. Studies have shown that ultrasonic treatment can enhance the effectiveness of marinades by increasing their penetration depth (Shi et al., 2020). Ultrasonic tenderization can be applied independently or in conjunction with conventional methods. Typically, a treatment of 10-30 minutes with ultrasonic probes or ultrasonic water baths at 20-100 kHz is sufficient (Dong et al., 2022). However, this can vary based on the technical specifications of the ultrasound device (such as frequency, power, and volume) as well as the amount and characteristics of the product being processed.

3.4. Cutting

Cutting is performed in various ways in gastronomy and culinary applications. This process includes slicing (thin slicing), chopping (cutting into small pieces), dicing (cutting into cubes), carving (creating decorative shapes from fruits and vegetables), splitting (filleting fish or separating large pieces of meat), and julienning (cutting food into thin, matchstick-like strips). These techniques are essential for food preparation, ensuring uniformity, and enhancing presentation and flavor distribution.

Ultrasonic cutting can be applied to a variety of cutting operations in the culinary field. These methods include slicing (clean, precise slices of bakery products), portioning (accurate cuts of fish, meat, and cheese), dicing (uniform cubes from fruits, vegetables, and meats), shaping (intricate designs from soft foods), and cutting layered products (ideal for desserts and filled products without smearing or mixing layers). This technique highlights its versatility and precision in culinary practices.

Ultrasonic cutting is a technique that uses high-frequency sound waves to facilitate the cutting of food products. In this method, an ultrasonic knife or cutter operates with high-frequency vibrations to produce smooth and clean cuts. The high-frequency vibrations reduce the force required for cutting, minimizing deformation and adhesion of the food product to the cutting tool. Ultrasonic cutting can be applied to a wide range of culinary products, including bakery items (e.g., bread, pastries, pies, cakes, tarts, meringues, and biscuits), frozen products (e.g., ice cream, cream cakes, pies, and sorbets), and fresh products (fish, meat, vegetables, fruits, bread) (Rawson, 1998: 256; Taha et al., 2024).

Ultrasonic cutting is especially advantageous for foods that are challenging to cut with traditional methods, such as those that are very soft, sticky, or have multiple layers. Furthermore, ultrasonic cutting has been shown to preserve the structural integrity and quality of food items better than conventional cutting methods, as it reduces the occurrence of smearing and contamination, making it an important tool in high-precision culinary applications (Taha et al., 2024).

3.5. Dehydration

Dehydration is the process of removing water from food products to preserve them and extend their shelf life. In gastronomy, dehydration or semi-dehydration is used to create ingredients that can be used in creative culinary applications without losing their nutritional value or flavor, such as dried fruits, vegetables, and meats. This technique is also applied in various culinary preparations to enhance dishes' flavors and textures by concentrating the ingredients' natural sugars and flavors.

Ultrasonic dehydration, a novel method, utilizes high-frequency sound waves to enhance the efficiency of the dehydration process. This technique improves mass transfer, significantly reducing drying times and energy consumption. Research has shown that ultrasonic dehydration maintains the nutritional and sensory qualities of food better than traditional dehydration methods (Baslar et al., 2015; Baslar et al., 2016). For example, a study by Tekin et al. (2017) showed that ultrasonic-assisted dehydration of green beans preserved more of their antioxidant activity and color than conventional air drying methods.

3.6. Rehydration

Rehydration is the process of restoring dried food products to a state close to their original form by accelerating their water absorption. This process is essential in culinary applications, particularly for preparing dried legumes, fruits, and vegetables, making them easier to use in various dishes and optimizing preparation time. Rehydration also shortens cooking times and ensures a more homogeneous texture in foods.

Ultrasound, which improves mass transfer, significantly reduces the hydration time by allowing water to penetrate the cellular structure of food products more quickly through high-frequency sound waves. This technique shows great potential for culinary applications, effectively improving the rehydration process of dried legumes, fruits, vegetables, and similar products. In addition to shortening the water absorption process, ultrasound can also reduce the cooking time of dried legumes (Ghafoor et al., 2014).

3.7. Diagnostic

Ensuring the quality and safety of food products in gastronomy and culinary applications is paramount. Diagnostic ultrasound, a non-invasive, rapid, and accurate method, is increasingly being adopted for various applications within this field, ranging from quality control to process optimization.

The application of diagnostic ultrasound in gastronomy and culinary practices covers several crucial areas. It enhances quality control by detecting inconsistencies in texture, composition, and density of food products, ensuring uniform quality and identifying defects in fruits, vegetables, meats, and dairy products. Ultrasonic waves assess the freshness and ripeness of produce by analyzing internal structures, helping ensure fresh produce for consumers (Srivastava & Sadistap, 2018; Gaete-Garretón et al., 2005). Additionally, it analyzes the composition of food items, such as fat in meat, sugar in fruits, and moisture in grains, aiding in maintaining nutritional standards and regulatory compliance (Nazir & Azaz Ahmad Azad, 2019). Furthermore, ultrasound can be used to analyze and evaluate the quality of frying oil (Izbaim et al., 2010).

3.8. Homogenization and Emulsification

Homogenization and emulsification processes have extensive applications in food processing. Homogenization involves dispersing one liquid into another immiscible liquid in the form of small particles. This technique is applied in various food creations, ranging from dairy items to soups and sauces. Homogenization, in dairy products, disrupts fat globules, ensuring that milk remains homogeneous for an extended period and provides a smoother texture (Sharma, 2017). Ultrasonic homogenization can be used in culinary practices due to its efficiency and effectiveness. This method uses high-frequency sound waves to create intense pressure variations, leading to the disruption of particles and fat globules at a microscopic level. Ultrasonic homogenization not only ensures a finer and more stable emulsion but also helps retain the ingredients' nutritional and sensory qualities (Patist & Bates, 2008). This technique is particularly useful in creating smooth textures in sauces, soups, and beverages, enhancing the overall quality of culinary products.

On the other hand, emulsification is the process of creating a stable mixture of two immiscible liquids, typically oil and water. This process is particularly critical in emulsion applications, such as sauces, salad dressings, mayonnaise, and ice cream. Ultrasonic emulsification enhances the rapid and effective mixing of oil and water phases, producing more stable and homogeneous emulsions (Taha et al., 2020). Moreover, emulsification helps in developing the desired texture and flavor profiles in chocolates and other confections. Therefore, this method can be an alternative for achieving high-quality and consistent culinary products.

3.9. Molecular Gastronomy

Molecular gastronomy is a discipline that combines scientific principles with culinary arts to understand the physical and chemical properties of foods and develop innovative cooking techniques. Integrating ultrasound technology into these techniques opens new avenues for both scientific and gastronomic innovations. Ultrasound technology, using high-frequency sound waves, can alter the internal structure of foods, improve mass transfer, and accelerate various chemical reactions, making it a transformative tool in many areas of molecular gastronomy.

Ultrasound technology can support molecular gastronomy in processes, such as foaming, gelation, component extraction, homogenization, emulsification, marination, and tenderization. By applying high-frequency vibrations to liquids, ultrasound technology creates microbubbles, facilitating the rapid and efficient formation of light and airy foams. Ultrasonic foaming produces more stable and homogeneous foams than traditional methods, offering superior aesthetics and flavor in culinary presentations (Chemat et al., 2011).

Gel formation is a fundamental technique in molecular gastronomy. Ultrasound optimizes the gelation process by accelerating gel formation and creating more homogeneous gel structures. High-frequency sound waves enable faster dissolution of gelatin and quicker gel setting, allowing chefs to create sophisticated gel structures more rapidly and efficiently (Caporaso & Formisano, 2016).

Ultrasound is highly effective in extracting aromatic compounds from plants and spices. The technology disrupts plant cell walls, allowing faster and more efficient extraction of active compounds. This method uses less solvent and shorter processing times than traditional extraction techniques, enhancing the intensity of aromatic components (Chemat et al., 2017). The integration of ultrasound technology into molecular gastronomy facilitates innovative applications in this field. The speed, efficiency, and quality improvements provided by ultrasonics enable chefs and food scientists to prepare more sophisticated, creative, and flavorful dishes. This integration enhances the potential of molecular gastronomy, paving the way for new and exciting discoveries in the culinary world.

4. Conclusions

The integration of ultrasound technology into gastronomy represents a significant advancement in culinary science and practice. This review has indicated that ultrasound provides various benefits and applications across various culinary processes, including decontamination, marination, tenderization, cutting, diagnostic analysis, homogenization, emulsification, dehydration, rehydration, and molecular gastronomy.

Ultrasound technology enhances food safety through effective decontamination methods, reducing microbial loads and chemical residues on food surfaces. In marination and tenderization, ultrasound accelerates the infusion of flavors and softens meat textures, thereby improving the overall quality and sensory attributes of food. The precision and efficiency of ultrasonic cutting make it ideal for processing delicate and multilayered foods, ensuring clean cuts and preserving food integrity. In diagnostic applications, ultrasound allows for non-invasive, rapid, and accurate assessments of food quality, including texture, composition, and ripeness. The innovative use of ultrasound in dehydration and rehydration processes optimizes drying times and improves the reconstitution of dried foods, preserving their nutritional and sensory qualities. Furthermore, ultrasonic homogenization and emulsification enhance the stability and consistency of emulsions, which is crucial for creating high-quality sauces, dressings, and dairy products. In the realm of molecular gastronomy, ultrasound opens new avenues for creativity, enabling chefs to develop unique textures, flavors, and presentations through techniques, such as foaming, gelation, and component extraction.

This study highlights the potential of ultrasound technology in gastronomy. Its ability to induce physical and chemical changes in food through high-frequency sound waves makes it an invaluable tool for modern culinary applications. As the technology continues to evolve, ultrasound is expected to revolutionize gastronomic practices further, leading to more innovative, efficient, and high-quality food preparation methods.

In conclusion, the integration of ultrasound technology in gastronomy not only enhances the sensory and aesthetic qualities of food but also contributes to the development of safer, more efficient, and more creative culinary techniques. Future research and continued integration of ultrasound technology will undoubtedly expand its applications, offering exciting opportunities for culinary scientists and chefs to push the boundaries of modern gastronomy. Thus, while ultrasound technology stands as a pivotal advancement poised to redefine the future of culinary arts, further research is essential to fully understand and maximize its potential in gastronomic applications.

Declaration of Competing Interest

The author declares that they have no financial or non-financial competing interests.

Author's Contributions

M. Başlar (0000-0002-8369-0769): *Definition, Data Collection, Investigation, Conceptualization, Writing, Methodology, Supervision, Editing*.

References

Başlar, M., Toker, Ö.S., Karasu, S., Tekin, Z., Biranger-Yıldırım, H. (2016). Ultrasound application for food dehydration. In M. Ashokkumar (Ed.): Handbook on Ultrasonics and Sonochemistry, Springer:USA.

Başlar, M., Kılıçlı, M., & Yalınkılıç, B. (2015). Dehydration kinetics of salmon and trout fillets using ultrasonic vacuum drying as a novel technique. Ultrasonics Sonochemistry, 27, 495-502.

Caporaso, N., & Formisano, D. (2016). Developments, applications, and trends of molecular gastronomy among food scientists and innovative chefs. Food Reviews International, 32(4), 417-435.

Cengiz, M. F., Başlar, M., Basançelebi, O., & Kılıçlı, M. (2018). Reduction of pesticide residues from tomatoes by low intensity electrical current and ultrasound applications. Food chemistry, 267, 60-66.

Chavan, P., Sharma, P., Sharma, S. R., Mittal, T. C., & Jaiswal, A. K. (2022). Application of high-intensity ultrasound to improve food processing efficiency: A review. Foods, 11(1), 122.

Chemat, F., & Khan, M. K. (2011). Applications of ultrasound in food technology: Processing, preservation and extraction. Ultrasonics sonochemistry, 18(4), 813-835.

Chemat, F., Rombaut, N., Sicaire, A. G., Meullemiestre, A., Fabiano-Tixier, A. S., & Abert-Vian, M. (2017). Ultrasound assisted extraction of food and natural products. Mechanisms, techniques, combinations, protocols and applications. A review. Ultrasonics sonochemistry, 34, 540-560.

Çimen, N., Unal, K., & Alp, H. (2024). Effects of ultrasound-assisted marination on spent hen meats: Microstructure, textural and technological properties. Food Bioscience, 104563.

Dong, Y., Zhang, H., Mei, J., Xie, J., & Shao, C. (2022). Advances in application of ultrasound in meat tenderization: A review. Frontiers in Sustainable Food Systems, 6, 969503.

Ertugay, M. F., & Başlar, M. (2014). The effect of ultrasonic treatments on cloudy quality-related quality parameters in apple juice. Innovative Food Science & Emerging Technologies, 26, 226-231.

Feng, H. & Yang, W., (2011). Ultrasonic processing. In H.Q. Zhang, G.V. Barbosa-Cánovas, V.M.B. Balasubramaniam , C.P. Dunne, D.F. Farkas, J.T.C. Yuan: Nonthermal Processing Technologies for Food. Blackwell Publishing, USA.

Gaete-Garretón, L., Vargas-Hernndez, Y., León-Vidal, C., & Pettorino-Besnier, A. (2005). A novel noninvasive ultrasonic method to assess avocado ripening. Journal of Food Science, 70(3), E187-E191.

Ghafoor, M., Misra, N. N., Mahadevan, K., & Tiwari, B. K. (2014). Ultrasound assisted hydration of navy beans (*Phaseolus vulgaris*). Ultrasonics Sonochemistry, 21(1), 409-414.

González-González, L., Luna-Rodríguez, L., Carrillo-López, L. M., Alarcón-Rojo, A. D., García-Galicia, I., & Reyes-Villagrana, R. (2017). Ultrasound as an alternative to conventional marination: Acceptability and mass transfer. Journal of Food Quality, 2017(1), 8675720.

Izbaim, D., Faiz, B., Moudden, A., Taifi, N., & Aboudaoud, I. (2010). Evaluation of the performance of Frying Oils using an ultrasonic technique. Grasas y aceites, 61(2), 151-156.

Jay, J. M. (2000). Modern Food Microbiology. Aspen Publishers.

Kilicli, M., Baslar, M., Durak, M. Z., & Sagdic, O. (2019). Effect of ultrasound and low-intensity electrical current for microbial safety of lettuce. LWT, 116, 108509.

Mason, T.J., Riera E., Vercet A. and Lopez-Buesa, P., 2005. Application of ultrasound. In D.W. Sun (Ed): Emerging technology for food processing, Elsevier Academic Press, Londra.

McClements, D. J. (1995). Advances in the application of ultrasound in food analysis and processing. Trends in Food Science & Technology, 6(9), 293-299.

Nazir, S., & Azaz Ahmad Azad, Z. R. (2019). Ultrasound: A food processing and preservation aid. Health and Safety Aspects of Food Processing Technologies, 613-632.

Patist, A., & Bates, D. (2008). Ultrasonic innovations in the food industry: From the laboratory to commercial production. Innovative Food Science & Emerging Technologies, 9(2), 147–154.

Raj, P. M. H., Mandal, P. K., Sen, A. R., Kasthuri, S., & Muthukumar, M. (2023). Effect of Marination on Meat Quality and Food Safety–a Review. Journal of Meat Science, 18(1), 75-90.

Rawson, F. F. (1998). An introduction to ultrasonic food cutting. In M. J. W. Povey & T.J. Mason (Eds.), Ultrasound in food processing (pp. 254–269). London: Blackie Academic.

Santos, H.M., Lodeiro, C., and Capelo-Martinez, J.L., 2009. The power of ultrasound. Ed. José-Luis Capelo-Martínez, Ultrasound in Chemistry: Analytical Applications. USA: Wiley.

Shi, H., Zhang, X., Chen, X., Fang, R., Zou, Y., Wang, D., & Xu, W. (2020). How ultrasound combined with potassium alginate marination tenderizes old chicken breast meat: Possible mechanisms from tissue to protein. Food Chemistry, 328, 127144.

Srivastava, S., & Sadistap, S. (2018). Non-destructive sensing methods for quality assessment of on-tree fruits: a review. Journal of Food Measurement and Characterization, 12(1), 497-526.

Taha, A., Mehany, T., Pandiselvam, R., Anusha Siddiqui, S., Mir, N. A., Malik, M. A., ... & Hu, H. (2024). Sonoprocessing: mechanisms and recent applications of power ultrasound in food. Critical reviews in food science and nutrition, 64 (17), 6016–6054.

Taha, A., Ahmed, E., Ismaiel, A., Ashokkumar, M., Xu, X., Pan, S., & Hu, H. (2020). Ultrasonic emulsification: An overview on the preparation of different emulsifiers-stabilized emulsions. Trends in Food Science & Technology, 105, 363-377.

Tekin, Z.H., Başlar, M., Karasu, S., Kilicli, M. (2017). Dehydration of green beans using ultrasound-assisted vacuum drying as a novel technique: Drying kinetics and quality parameters. Journal of Food Processing and Preservation, 41(6): e13227.

Weiss, J., Gulseren, I. and Kjartansson, G., 2011. Physicochemical effects of high-intensity ultrasonication on food poteins and carbonhidrates. Nonthermal processing Technologies for Food, Eds: H.Q. Zhang, G.V. Barbosa-Cánovas, V. M. B. Balasubramaniam, C. P. Dunne, D.F. Farkas, J.T.C. Yuan. Blackwell Publishing, USA.