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The Role Of Stability Testing In Determining The Shelf Life And Storage Conditions Of Pharmaceutical Products: A Narrative Review

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Abstract
Stability testing plays an important role in determining the shelf life and appropriate storage conditions of pharmaceutical products. This narrative review aimed to evaluate the role of Stability testing in maintaining the quality, safety, and effectiveness of pharmaceutical products during storage and distribution. Literature was collected from scientific databases including Google Scholar, PubMed, ScienceDirect, and ResearchGate using keywords related to Stability testing and pharmaceutical storage. The reviewed studies showed that Stability testing, including long-term, accelerated, intermediate, and forced degradation studies, can evaluate physical, chemical, and microbiological changes caused by environmental factors such as temperature, humidity, light, and oxidation. Several studies reported that high temperature and humidity accelerated drug degradation, while appropriate storage conditions maintained product stability within pharmacopeial specifications. Stability data are also essential for determining expiration dates, packaging selection, and storage instructions. Therefore, Stability testing is a crucial scientific approach in the pharmaceutical industry to ensure product quality, regulatory compliance, and patient safety throughout the product shelf life.

Keywords: Pharmaceuticals, Shelf-life, Storage, Stability, Degradation

INTRODUCTION

Pharmaceutical products must maintain their quality, safety, and efficacy throughout the storage process until they are used by patients. To ensure this, testing is required to evaluate the stability of products against environmental influences such as temperature, light, humidity, and oxygen. This testing is known as stability testing, which refers to a series of tests conducted to determine the ability of a pharmaceutical product to maintain its physical, chemical, microbiological, and therapeutic characteristics over a specified storage period. Stability testing is an essential part of pharmaceutical product development because the results are used to ensure that products continue to meet quality standards until the end of their shelf life (Chew *et al*., 2021).

Stability testing plays an important role in determining the shelf life and safety of drug use. The determination of shelf life is one of the main objectives of stability testing. Shelf life refers to the period during which a pharmaceutical product still meets established quality specifications when stored under defined conditions. Products that undergo degradation may lead to reduced therapeutic effectiveness, changes in the physical properties of the formulation, and even the formation of potentially toxic compounds for patients. Therefore, stability testing data are used by the pharmaceutical industry as a basis for establishing expiration dates and ensuring product quality during distribution and storage (Zothanpuii *et al*., 2020).

Stability testing also plays a role in determining appropriate storage conditions for pharmaceutical products. Storage conditions greatly influence product stability because each formulation has different stability characteristics depending on the active ingredients, excipients, dosage form, and packaging type used. Some products can be stored at room temperature, while others require special protection from light, humidity, or low temperatures to maintain their quality. Stability testing is generally conducted according to the guidelines of the International Council for Harmonisation (ICH), which include long-term stability testing, accelerated testing, and intermediate testing. These tests help the pharmaceutical industry predict product stability more efficiently and

determine appropriate storage conditions to maintain product quality during distribution and use (González *et al*., 2022).

The increasing global distribution of pharmaceutical products and variations in environmental conditions during storage and transportation have made stability data increasingly important in the modern pharmaceutical industry. In addition, the development of pharmaceutical formulations and technologies means that each product has different stability characteristics, requiring appropriate testing approaches. In modern pharmaceutical industries, stability testing is not only used to meet regulatory requirements but also plays an important role in formulation development, packaging selection, and product quality assurance throughout distribution and use.

Although numerous studies on stability testing have been conducted, most research has focused on testing methods or the evaluation of specific products individually. Studies that examine the relationship between stability testing results and the determination of shelf life and storage conditions across various pharmaceutical dosage forms remain limited. Therefore, a comprehensive review is needed to provide an overall understanding of the influence of environmental factors on pharmaceutical product stability and the role of stability testing in supporting shelf life determination and storage condition establishment. Based on this description, this article is written in the form of a narrative review aimed at examining the role of stability testing in determining the shelf life and storage conditions of pharmaceutical products based on recent scientific literature.

RESEARCH METHODS

The research method used in this study is a narrative review, which is a method conducted by collecting, reviewing, comparing, and synthesizing various previous research findings related to the role of stability testing in determining the shelf life and storage conditions of pharmaceutical products. This study uses secondary data obtained from various scientific literature sources, such as national and international journals, research articles, and other relevant scientific references. The literature search process was carried out through electronic databases such as Google Scholar, PubMed, ScienceDirect, and ResearchGate using the keywords “Pharmaceuticals,” “Expiration,” “Storage,” “Stability,” and “Degradation.”

The initial stage of the study involved searching for and collecting articles discussing the role of stability testing in determining the shelf life and storage conditions of pharmaceutical products. The selected literature consisted of articles relevant to the research topic, published between 2019 and 2026, available in full-text form, and containing information on types of stability testing, storage conditions, observed parameters, and the results of pharmaceutical product stability testing. Articles that were not relevant to the topic, lacked complete data, or were only literature reviews without research data were excluded from this study.

Based on the initial search results, a number of articles were obtained from various databases, which were then filtered according to the established criteria until 15 articles met the requirements for further analysis. The selected articles were then reviewed and systematically organized in a table containing the author’s name and year of publication, sample type, type of stability testing, storage conditions, observed parameters, and main research findings. The table was prepared to facilitate comparison and data analysis from each study related to the role of stability testing in determining the stability, shelf life, and storage conditions of pharmaceutical products.

The collected data were then analyzed descriptively and qualitatively by comparing the results of studies from various journals used. Subsequently, the analysis results were presented in narrative form to provide an overview of the importance of stability testing in maintaining the quality, safety, and efficacy of pharmaceutical products during storage, as well as in accurately determining product shelf life.

RESULTS AND DISCUSSION

The results can be presented with support tables, graphics or images as needed, to clarify the

No	Author	Sample Type	Stability Testing Type	Storage Conditions (ICH)	Main Findings
1	Yulianita *et al*., 2021	Generic simvastatin tablets (10 mg & 20 mg)	Real-time stability + stress testing	Actual conditions: ≤25°C and ≥25°C; RH >65% for 6 months	A decrease in hardness and drug content occurred, but the products still met pharmacopeial specifications.
2	Rahmah *et al*., 2025	Chloramphenicol ear drops (liquid preparation)	Forced degradation (acid, base, heat)	0.1N HCl (80°C), 0.1N NaOH (80°C), heat at 90°C	The most significant degradation occurred under alkaline conditions and high temperatures.
3	Chaturvedi, 2025	Large-scale 500 mg immediate-release tablets	Long-term, intermediate, accelerated stability	25±2°C/60±5% RH; 30±2°C/65±5% RH; 40±2°C/75±5% RH for 6 months	The product maintained >95% assay under long-term conditions and was predicted to have a 24-month shelf life.
4	Sugindro, 2023	0.9% NaCl infusion 500 mL	Real-time stability test	40°C/75% RH	Drug content remained at 95–105%, and the product was predicted to have a shelf life of up to 5 years.
5	Oliva & Llabrés, 2023	Insulin preparations	Long-term stability study	22.7±1.6°C for 2 years	Statistical methods and process capability accurately predicted shelf life and product release limits.
6	Sugiharta & Ningsih, 2021	Ketoconazole cream	Long-term storage stability study (real-time stability study)	30 ± 2°C / RH 75 ± 5% for 42 months	Ketoconazole cream remained stable for 42 months, and all parameters met the established specifications.
7	Oloninefa *et al*., 2022	Various oral and topical pharmaceutical preparations	Real-time stability studies	Real-time storage conditions according to environmental factors	Most products remained within specifications despite reductions in potency and physical changes during storage.
8	Bhangare *et al*., 2022	APIs and pharmaceutical products	Forced degradation and kinetic studies	Temperature, pH, light, and humidity (non-specific ICH conditions)	Products demonstrated good stability during storage and were predicted to remain stable for approximately 1–2 years under suitable storage conditions.
9	Modhave *et al*., 2024	GLPG4399 capsules	Accelerated Stability Assessment Program (ASAP) and real-time stability study	Accelerated test: 40–70°C with RH 10–80% for up to 5 weeks; long-term test: 25 ± 3°C/60 ± 5% RH for up to 12 months	GLPG4399 capsules remained stable for up to 12 months at 25°C/60% RH. The ASAP method predicted a shelf life of approximately 1.5 years without desiccants.
10	Adha *et al*., 2025	Paracetamol tablets	Physical and chemical stability testing (real-time & accelerated)	Room temperature: 25°C ± 2°C; RH 60% ± 5% (long-term) and elevated temperature: 40°C ± 2°C; RH 75% ± 5% (accelerated)	At high temperatures, a 5.8% decrease in drug content, color changes (month 2), a 12.6% reduction in hardness, and a decrease in pH were observed; room temperature storage remained relatively stable.
11	Marlina, 2025	Paracetamol syrup	Physical and chemical stability testing	Room temperature 25–30°C for 1–3 months	Paracetamol syrup remained physically stable during storage, although a slight decrease in paracetamol content occurred over time.
12	Zulbeari & Holm, 2025	Cinnarizine suspension with polysorbate 20	Short-term stress study and long-term stability study	Storage at −18°C, 5°C, 25°C, and 40°C for up to 78 weeks	High storage temperatures accelerated suspension instability, whereas low temperatures improved long-term stability.

13	Masyhuda & Sukmawati, 2022	Compounded nevirapine pulveres	Physical and chemical stability testing	Room temperature 25°C and refrigerated temperature 4°C for 28 days	Nevirapine pulveres remained stable for 28 days at both 25°C and 4°C with no significant changes in content, pH, color, or odor.
14	Iudicello *et al*., 2021	Azacitidine/Vidaza® suspension 25 mg/mL	Physical, chemical, and microbiological stability testing	Stored at 2–8°C in original vials and polypropylene syringes for up to 96 hours according to ICH Q1A(R2) guidelines	Azacitidine suspension remained physically and microbiologically stable during refrigerated storage for up to 96 hours, with minimal degradation.
15	Lai *et al*., 2019	Naloxone hydrochloride ampoules	Heat and freeze-thaw stability study	80°C for 8 hours followed by room temperature for 16 hours; −20°C for 16 hours followed by 4°C for 8 hours for up to 28 days	Naloxone remained chemically stable. No significant decrease in concentration was observed, although slight paraben degradation was found at high temperatures.

Stability testing is one of the essential stages in the development and quality control of pharmaceutical products, conducted to evaluate changes in the quality of drug substances and drug products during storage due to environmental factors such as temperature, humidity, light, oxidation, and agitation. Based on the International Council for Harmonisation (ICH) Q1 guideline, stability testing aims to establish and ensure the re-test period or shelf life of a product so that its quality, safety, and efficacy are maintained throughout distribution and use. This testing includes long-term stability tests, accelerated stability tests, intermediate stability tests, photostability studies, as well as stress and forced degradation studies to determine the product's degradation profile and ensure that analytical methods are capable of accurately detecting quality changes. The results of stability testing are used as a basis for determining storage conditions, packaging systems, and the shelf life of pharmaceutical products (ICH, 2025).

In general, stability testing is divided into several types, namely long-term stability tests, accelerated stability tests, intermediate stability tests, and forced degradation studies. Long-term stability tests are conducted under normal storage conditions over an extended period to determine product shelf life. Accelerated stability tests are performed under high temperature and humidity conditions to speed up the degradation process so that shelf life prediction can be made more quickly. Intermediate stability tests are used when accelerated test results show significant changes, requiring intermediate storage conditions. Meanwhile, forced degradation studies are carried out under extreme conditions such as acid, base, oxidation, heat, or light exposure to determine the intrinsic stability of the active ingredient, identify degradation pathways, and ensure that analytical methods can accurately detect product quality changes (Nisa *et al*., 2025).

Based on findings from various studies, temperature is the most influential environmental factor affecting pharmaceutical product stability. An increase in temperature is known to accelerate chemical degradation reactions of drugs, such as hydrolysis, oxidation, and changes in the molecular structure of active substances. This is evident in the study by Adha *et al*. (2025), where paracetamol tablets stored at a high temperature of 40°C experienced a 5.8% decrease in content, color changes, and reduced tablet hardness compared to those stored at room temperature, which remained relatively stable. Similar results were reported by Zulbeari & Holm (2025), where high temperatures accelerated the instability of cinnarizine suspensions, while low-temperature storage improved long-term stability.

The effect of temperature on product stability is also influenced by the type of pharmaceutical dosage form. Liquid and suspension formulations are generally more susceptible to degradation compared to solid dosage forms because the active ingredient is in a dissolved state, making it more prone to chemical reactions. In a study by Iudicello *et al*. (2021), azacitidine suspension remained stable for only 96 hours under cold storage conditions (2–8°C), requiring specific storage conditions to maintain both chemical and microbiological stability. Meanwhile, a study by Masyhuda & Sukmawati (2022) on nevirapine powder compounding showed that the product remained stable at

both room temperature and cold storage for 28 days without significant changes in content, pH, color, or odor.

In addition to temperature, humidity also affects pharmaceutical product stability, particularly for solid dosage forms such as tablets and capsules. A study by Yulianita *et al*. (2021) on simvastatin tablets showed that storage under high relative humidity conditions led to decreased hardness, increased friability, and reduced active ingredient content, although it still met pharmacopoeial specifications. This is supported by Veronica *et al*. (2022), who stated that humidity is one of the main factors affecting pharmaceutical stability because it can trigger drug degradation through hydrolysis and other water-mediated reactions. Moisture may originate from the environment during production, storage, distribution, or from excipients themselves. Absorbed water increases molecular mobility, allowing greater interaction with the active substance and accelerating drug degradation. In addition to chemical degradation, humidity can also alter physical properties such as crystal form changes, reduced solubility, prolonged tablet disintegration time, and decreased therapeutic effectiveness.

The review also shows that various types of stability testing can be used to determine pharmaceutical product shelf life. Long-term stability studies and accelerated stability studies are the most commonly used methods because they reflect product stability under real storage conditions as well as under accelerated conditions. In a study by Chaturvedi (2025), immediate-release 500 mg tablets tested under long-term conditions (25±2°C/60±5% RH) and accelerated conditions (40±2°C/75±5% RH) for six months maintained an assay content above 95%, suggesting a predicted shelf life of up to 24 months. In addition, Sugindro (2023) reported that 0.9% NaCl infusion remained within specification for content and sterility under 40°C/75% RH storage conditions, with an estimated shelf life of up to five years. These findings indicate that stability data can be used to objectively predict product shelf life based on changes in quality parameters during storage.

In addition to conventional methods, advancements in modern pharmaceutical technology have also encouraged the use of faster and more efficient approaches such as the Accelerated Stability Assessment Program (ASAP). This method utilizes degradation kinetics and the Arrhenius equation to estimate product shelf life based on the relationship between temperature, humidity, and active ingredient degradation rate. A study by Modhave *et al*. (2024) using the ASAP approach successfully predicted the shelf life of GLPG4399 capsules to be approximately 1.5 years based on oxidative degradation parameters and Arrhenius kinetics.

Besides long-term and accelerated testing, forced degradation studies also play a crucial role in pharmaceutical product stability evaluation. These studies are conducted under extreme conditions such as acid, base, heat, light, and oxidation to determine degradation pathways of the active substance and to establish stability-indicating analytical methods. A study by Rahmah *et al*. (2025) showed that chloramphenicol ear drops experienced the highest degradation under alkaline and high-temperature conditions. This information is important in formulation development and storage condition selection, as it helps the pharmaceutical industry identify the most critical factors that may cause product deterioration. Forced degradation studies are also essential in validating analytical methods such as HPLC and spectrophotometry to ensure that the methods can distinguish active ingredients from their degradation products.

Modern pharmaceutical technological advancements have shifted stability testing approaches from conventional observation to statistical and kinetic modeling approaches. A study by Oliva & Llabrés (2023) explained that the use of process capability analysis and HPLC validation can improve the accuracy of shelf life and release limit predictions for insulin formulations. Furthermore, the Accelerated Stability Assessment Program (ASAP) allows faster shelf life prediction compared to conventional methods by utilizing the relationship between temperature, humidity, and drug degradation kinetics. This approach significantly supports pharmaceutical industries in accelerating product development without compromising quality and safety. Bhangare *et al*. (2022) also stated that degradation kinetics approaches can be used to determine t90 values and activation energy, making shelf life prediction more scientific and objective.

Overall, differences in research findings indicate that pharmaceutical product stability is influenced not only by temperature and humidity but also by the characteristics of the active ingredient, dosage form, packaging system, and testing methods used. Stability data are not only used to meet regulatory requirements but also serve as a scientific basis for packaging selection, distribution control, and storage instruction labeling. Products stored under inappropriate conditions are at risk of degradation, which may reduce therapeutic effectiveness and compromise patient safety.

CONCLUSION

Based on the narrative review, it can be concluded that temperature and humidity are the main factors affecting the stability of pharmaceutical products during storage because they can cause physical, chemical, and microbiological changes in the product. Various stability testing methods, such as long-term stability studies, accelerated stability studies, and forced degradation studies, have proven effective in evaluating stability and predicting the shelf life of pharmaceutical products more quickly and scientifically. The study also shows that proper storage conditions, including the use of cold temperatures for certain products, can maintain product quality and effectiveness throughout the shelf life. Stability testing plays a crucial role in the pharmaceutical industry as a basis for determining expiration dates, selecting packaging, and determining storage conditions to ensure the quality, safety, and effectiveness of pharmaceutical products during distribution and use.

REFERENCES

Adha, M. H., Jaida Rahma, & Nor Latifah. (2025). Uji Stabilitas Fisik dan Kimia Sediaan Tablet Paracetamol terhadap Suhu dan Kelembaban Selama Penyimpanan. *Jurnal Sains Farmasi Dan Kesehatan*, *3*(1), 78–81. https://doi.org/10.62379/jfkes.v3i1.3034

Bhangare, D., Rajput, N., Jadav, T., Sahu, A. K., Tekade, R. K., & Sengupta, P. (2022). Systematic Strategies for Degradation Kinetic Study of Pharmaceuticals: an Issue of Utmost Importance Concerning Current Stability Analysis Practices Analysis Practices. *Journal of Analytical Science and Technology*, *13*(1). https://doi.org/10.1186/s40543-022-00317-6

Chaturvedi, R. (2025). Stability Profiling and Shelf - Life Prediction of Large - Scale Batch - Manufactured Pharmaceuticals under ICH Conditions. *Journal of Industrial Pharmacy and Drug Management*, *01*(01), 32–40.

Chew, Y. L., Khor, M. A., & Lim, Y. Y. (2021). Choices of Chromatographic Methods as Stability Indicating Assays for Pharmaceutical Products: A Review. *Heliyon*, *7*(3), 1–12. https://doi.org/10.1016/j.heliyon.2021.e06553

González, O. G., Ramirez, I. O., Ramirez, B. I., Connell, P. O., Ballesteros, M. P., Torrado, J. J., & Serrano, D. R. (2022). Drug Stability : ICH versus Accelerated Predictive Stability Studies. *Pharmaceutics*, *14*(11), 1–21. https://doi.org/10.3390/pharmaceutics14112324

Iudicello, A., Genovese, F., Strusi, V., Dominici, M., & Ruozi, B. (2021). Development and Validation of a New Storage Procedure to Extend the In-Use Stability of Azacitidine in Pharmaceutical Formulations. *Pharmaceuticals*, *14*(9). https://doi.org/10.3390/ph14090943

Lai, D., Pham, A. T., Nekkar Rao, P. P., & Beazely, M. A. (2019). The Effects of Heat and Freeze-Thaw Cycling on Naloxone Stability. *Harm Reduction Journal*, *16*(1), 1–7. https://doi.org/10.1186/s12954-019-0288-4

Marlina, S. (2025). Studi Stabilitas Fisik dan Kimia Sediaan Sirup Parasetamol pada Penyimpanan Suhu Ruang. *Jurnal Farmasi Dan Kesehatan Indonesia*, *01*(1), 8–14. https://ejournal.samudrailmu.com/index.php/jfki

Masyhuda, A., & Sukmawati, A. (2022). Uji Stabilitas Fisik dan Kimia Sediaan Racikan Pulveres Nevirapine. *Usadha: Journal of Pharmacy*, *1*(3), 278–290.

https://doi.org/10.23917/ujp.v1i3.89

Modhave, D., Vrielynck, S., & Roeleveld, K. (2024). Assessing Drug Product Shelf Life Using the Accelerated Stability Assessment Program: A Case Study of a GLPG4399 Capsule Formulation. *Pharmaceutics*, *16*(11). https://doi.org/10.3390/pharmaceutics16111400

Nisa, J., Saputra, N., & Latifah, N. (2025). Uji Stabilitas Obat Sediaan Tablet : Prinsip , Pedoman ICH Q1 , dan Parameter Kritis. *OBAT: Jurnal Riset Ilmu Farmasi Dan Kesehatan*, *3*(4). https://doi.org/10.61132/obat.v3i4.1507

Oliva, A., & Llabrés, M. (2023). Drug Shelf Life and Release Limits Estimation Based on Manufacturing Process Capability. *Pharmaceutics*, *15*(4). https://doi.org/10.3390/pharmaceutics15041070

Oloninefa, S. D., J. E, A., A. J, A., D. O, A., M. E, A., A. I, A., & A. A, A. (2022). Implication of Data Obtained from Real Time Stability Studies of Pharmaceutical Preparations. *Research Journal of Pharmacology and Pharmacodynamics*, *14*(4), 199–207. https://doi.org/10.52711/2321-5836.2022.00035

Rahmah, A., Hendra Wijaya, T., & Wasito, H. (2025). Degradation and Stability Testing of Chloramphenicol Ear Drops Using Derivative Spectrophotometry Combined with Chemometrics. *Jurnal Ilmiah Farmasi (Scientific Journal of Pharmacy)*, *21*(1), 41–57. http://journal.uii.ac.id/index.php/JIF

Sugiharta, S., & Ningsih, W. (2021). Evaluasi Stabilitas Sifat Fisika Kimia Sediaan Krim Ketoconazole dengan Metode Stabilitas Penyimpanan Jangka Panjang. *Majalah Farmasetika*, *6*(1), 162–175. https://doi.org/10.24198/mfarmasetika.v6i0.36707

Sugindro. (2023). Validasi Proses Sterilisasi Menggunakan Otoklaf Dan Uji Stabilitas Real Time Infus Nacl 0,9 % 500 Ml Lembaga Biomedis. *Jurnal Kesehatan D*, *7*(1), 155–159. https://doi.org/10.37337/jkdp.v0i0.383 %5C

Veronica, N., Heng, P. W. S., & Liew, C. V. (2022). Ensuring Product Stability − Choosing the Right Excipients. *Journal of Pharmaceutical Sciences*, *111*(8), 2158–2171. https://doi.org/10.1016/j.xphs.2022.05.001

Yulianita, R., Sopyan, I., Gazzali, A. M., & Muchtaridi, M. (2021). A Novel Stability Study of Simvastatin Generic Tablet in Public Pharmacy Facilities of Purwakarta, Indonesia. *Indonesian Journal of Pharmacy*, *32*(4), 458–462. https://doi.org/10.22146/ijp.2730

Zothanpuii, F., Rajesh, R., & Selvakumar, K. (2020). A Review on Stability Testing Guidelines of Pharmaceutical Products. *Asian Journal of Pharmaceutical and Clinical Research*, *13*(10). https://doi.org/10.22159/ajpcr.2020.v13i10.38848

Zulbeari, N., & Holm, R. (2025). Long-Term versus Short-Term Stress Physical Stability Assessment of Pharmaceutical Nano- and Microsuspensions. *International Journal of Pharmaceutics*, *677*(125646). https://doi.org/10.1016/j.ijpharm.2025.125646