E-ISSN 2250-0944

ISSN 2250-1150

doi: 10.48047/ijprt/15.01.32

Comparing DNA Degradation Rates Under Different Environmental Conditions: A Controlled Study

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Abstract

DNA degradation is a critical factor in the preservation and analysis of biological samples. Environmental conditions such as temperature, humidity, and UV exposure significantly influence the stability of DNA. This study aimed to investigate the degradation rates of DNA under different environmental conditions, including controlled temperature, humidity, and varying exposure to ultraviolet (UV) radiation. DNA samples extracted from human blood were exposed to a range of environmental conditions in a controlled laboratory setting. The degradation was measured by analyzing DNA integrity using gel electrophoresis and quantitative PCR over a six-week period. The results showed that UV radiation significantly accelerated DNA degradation compared to other environmental factors, with the most notable decrease in DNA yield observed at higher temperatures and in high humidity environments. Statistical analysis revealed a significant difference in degradation rates between groups exposed to UV and those under controlled conditions ($p < 0.05$). These findings emphasize the importance of environmental control in DNA preservation. The study concludes that minimizing exposure to UV radiation and extreme temperatures can substantially enhance DNA preservation for forensic and research applications.

Keywords: DNA degradation, environmental conditions, UV radiation.

Introduction

DNA degradation, a natural process that occurs post-mortem or due to environmental exposure, can hinder the quality and quantity of genetic material available for analysis. As a result, understanding the factors that influence DNA degradation is crucial for fields such as forensic science, archaeology, and biobanking. Previous research has shown that environmental factors such as temperature, humidity, and exposure to UV radiation are key contributors to DNA degradation (1). DNA, being a complex biomolecule, is highly susceptible to damage caused by environmental stressors, especially in the presence of UV light and elevated temperatures. This degradation results from various processes, including hydrolytic cleavage, oxidation, and photodamage, which ultimately lead to the fragmentation of the DNA backbone (2, 3).

The importance of DNA preservation is particularly evident in forensic science, where biological samples collected from crime scenes must be stored under optimal conditions to ensure DNA can be successfully extracted and analyzed. Similarly, in archaeological studies, ancient DNA is often fragmented and degraded, posing challenges for extracting usable genetic information (4). Previous studies have shown that temperature plays a major role in DNA degradation, with higher temperatures accelerating the process (5). Likewise, humidity levels can impact the stability of DNA, as water molecules can promote hydrolytic cleavage of the DNA backbone (6).

UV radiation, a known mutagenic agent, has also been shown to damage DNA by inducing the formation of pyrimidine dimers, which interfere with normal replication and transcription processes (7). Despite the recognized importance of these factors, there is a need for more controlled studies to compare the impact of temperature, humidity, and UV exposure on DNA degradation under real-world conditions. This study aims to fill this gap by assessing the degradation rates of DNA samples exposed to varying environmental conditions.

Objective

This study aimed to investigate and compare the rates of DNA degradation under controlled conditions with respect to temperature, humidity, and UV exposure. The study's objectives were as follows:

1. To evaluate the impact of high and low temperatures on DNA integrity.
2. To examine the role of humidity in DNA degradation.
3. To assess the effect of UV radiation on DNA degradation compared to temperature and humidity alone.

4. To identify the environmental conditions that accelerate DNA degradation most significantly.

Methodology

A controlled experiment was conducted in KEMU Lahore Pakistan where DNA samples were exposed to different environmental conditions for six weeks. DNA was extracted from human blood samples using a standard phenol-chloroform method. The extracted DNA was quantified using a spectrophotometer, and its integrity was initially assessed using gel electrophoresis.

The study had four experimental groups:

1. **Controlled Group**: DNA stored at 4°C with low humidity and no UV exposure.
2. **Temperature Group**: DNA stored at 37°C with low humidity and no UV exposure.
3. **Humidity Group**: DNA stored at 4°C with high humidity (75%).
4. **UV Exposure Group**: DNA exposed to UV radiation ($\lambda = 254$ nm) at room temperature.

The degradation of DNA in each group was measured by performing gel electrophoresis every two weeks, tracking DNA fragmentation. Additionally, quantitative PCR was conducted to quantify the amount of intact DNA at each time point. The degradation rate was calculated by comparing the initial DNA yield to the yield after each exposure period. Statistical analysis was performed using SPSS software, and significance was determined using ANOVA, with a p-value of <0.05 considered statistically significant.

Sample size calculation was conducted using Epi Info software, assuming a 95% confidence interval and 80% power, to ensure that differences in DNA degradation rates between environmental conditions could be detected with sufficient statistical power.

Results

Table 1: **DNA Degradation Rate Over Time in Different Environmental Conditions**

Time Point (weeks)	Controlled Group (DNA Yield %)	Temperature Group (DNA Yield %)	Humidity Group (DNA Yield %)	UV Exposure Group (DNA Yield %)
0	100	100	100	100
2	98	87	94	70
4	97	76	89	55
6	95	63	85	35

Explanation:

The data shows that DNA degradation was most pronounced in the UV exposure group, with a significant reduction in DNA yield ($p < 0.05$). Temperature also had a noticeable effect, particularly in the 37°C group, where DNA yield dropped significantly over the 6-week period. Humidity showed a smaller but noticeable impact on degradation, with DNA in the high humidity group showing moderate degradation.

Table 2: **PCR Amplification of DNA at Different Time Points**

Group	**PCR Amplification (Ct Value)**	**p-value**
Controlled Group	18.2 ± 1.4	-
Temperature Group	21.5 ± 2.1	0.032
Humidity Group	20.1 ± 1.8	0.048
UV Exposure Group	24.3 ± 3.2	0.002

Explanation:

The PCR results corroborate the findings from the gel electrophoresis, with the UV exposure group exhibiting the highest Ct values, indicating significant degradation. The temperature and humidity groups also showed higher Ct values compared to the controlled group, although the effect was less pronounced than UV exposure.

Table 3: **Statistical Analysis of Degradation Rates**

Environmental Condition	**DNA Degradation Rate (%)**	**p-value**
Controlled	5.0 ± 2.1	-
Temperature	37.0 ± 3.5	0.01
Humidity	15.0 ± 2.8	0.03
UV Exposure	65.0 ± 6.2	< 0.001

Explanation:

Statistical analysis showed that UV exposure caused the most significant degradation, with the highest degradation rate (65%). Temperature and humidity also had significant effects, but their impact was less severe compared to UV exposure.

Discussion

The results of this study provide valuable insights into how environmental conditions—particularly temperature, humidity, and UV radiation—affect the rate of DNA degradation. Our study specifically focused on the degradation of DNA extracted from human blood under controlled conditions, revealing significant differences in degradation rates based on the exposure to various environmental stressors. This discussion elaborates on the findings, integrates them with existing literature, and emphasizes their implications for DNA preservation practices in fields such as forensic science, biobanking, and archaeology.

One of the most striking findings from our study was the significant impact of UV radiation on DNA degradation. DNA exposed to UV radiation experienced the most substantial decline in integrity, with a marked reduction in yield observed as early as two weeks into the study. This result is consistent with previous research highlighting UV radiation as a potent mutagen that induces DNA damage through the formation of pyrimidine dimers, which interfere with normal DNA replication and transcription processes (8, 9). UV-induced DNA damage is particularly concerning in forensic and archaeological applications, where DNA samples often undergo extended exposure to environmental elements. These findings suggest that samples exposed to sunlight or other sources of UV radiation are at a much higher risk of degradation, which can lead to a loss of valuable genetic information.

The temperature group in this study also demonstrated significant DNA degradation, particularly at 37°C. DNA samples stored at this higher temperature showed a marked reduction in DNA yield, with degradation rates increasing over the six-week period. This aligns with existing studies that have shown that elevated temperatures facilitate hydrolytic cleavage of the DNA backbone, leading to fragmentation (5, 11). Hydrolysis is a chemical process that breaks down the DNA structure, and it is exacerbated at higher temperatures due to increased molecular motion. As a result, DNA samples exposed to warm environments, such as those found in field collection or storage in non-ideal conditions, may experience rapid degradation, compromising the quality of genetic data extracted from them. These results suggest that maintaining samples at lower, more stable temperatures is essential to prevent DNA damage and preserve sample integrity.

Humidity also played a role in DNA degradation, albeit to a lesser extent than UV exposure and temperature. The high humidity group showed moderate degradation of DNA, with a steady decline in yield over the six-week period. This supports previous research indicating that high humidity levels can accelerate DNA degradation by promoting hydrolysis, as water molecules act as catalysts for the breakdown of the phosphodiester bonds within the DNA molecule (6, 12). The presence of water can increase the rate of depurination and strand scission, which is particularly problematic for DNA stored in moist or humid environments. While the effect of humidity was less pronounced than UV or temperature, the findings emphasize the importance of controlling humidity levels during DNA storage, especially in tropical or high-humidity regions where biological samples may be at higher risk of degradation.

Interestingly, the controlled group, which was stored at 4°C with low humidity and no UV exposure, showed minimal degradation over the study period, reinforcing the importance of maintaining a stable, low-temperature environment for DNA storage. This group retained more than 95% of the initial DNA yield by the end of the six-week period, underscoring the effectiveness of temperature control in preserving DNA integrity. These results are consistent with the widely accepted practice of storing biological samples at refrigerated or frozen temperatures to minimize degradation (13). The controlled group serves as a benchmark for optimal DNA preservation and demonstrates that environmental conditions can be manipulated to significantly prolong the stability of genetic material (14-18).

Our study contributes to the growing body of literature that emphasizes the importance of controlling environmental variables to minimize DNA degradation. While previous studies have addressed the individual effects of temperature, humidity, and UV exposure, our study is unique in its comprehensive comparison of these factors under controlled conditions. This holistic approach provides a more nuanced understanding of how these environmental factors interact and their combined effects on DNA stability. The results can inform best practices for DNA storage, handling, and analysis in various scientific disciplines, particularly in forensic and archaeological settings where DNA samples are often subjected to challenging environmental conditions(19-20), The findings also have significant implications for the field of biobanking, where DNA samples are often stored for long periods. Biobanks play a crucial role in preserving genetic material for research and clinical purposes, and maintaining the integrity of these samples is essential for ensuring that they remain viable for future analysis. The results of this study suggest that biobanks should prioritize temperature control and UV protection to mitigate DNA degradation over time. While the effects of humidity on DNA degradation were less significant, it may still be important for biobanks to monitor and control humidity levels, especially in regions with high ambient moisture.

In addition, these findings have practical implications for forensic science, where DNA evidence recovered from crime scenes is often exposed to varying environmental conditions. Samples collected from outdoor crime scenes, for example, may be subjected to high temperatures, humidity, and UV radiation, all of which could accelerate DNA degradation and compromise the integrity of the evidence. Our study underscores the need for careful handling and storage of forensic samples to prevent contamination and degradation. Forensic investigators may consider incorporating environmental control measures, such as refrigeration or UV-protective storage, into their protocols to improve the likelihood of obtaining high-quality DNA for analysis.

The results of this study also suggest that researchers working with ancient or degraded DNA in archaeological contexts may face significant challenges when attempting to extract viable genetic material. Ancient DNA is often fragmented and degraded due to prolonged exposure to environmental factors, including temperature fluctuations, humidity, and UV radiation. By understanding the degradation rates under different environmental conditions, researchers can refine their methods for extracting and analyzing ancient DNA, potentially improving the success rates of these studies.

While our study provides important insights, there are several limitations that should be considered. The study was conducted in a controlled laboratory setting, and while this allows for precise manipulation of environmental conditions, it may not fully replicate the complexity of natural environmental factors encountered in real-world scenarios. Future studies should consider evaluating DNA degradation rates under field conditions to better understand the degradation dynamics in natural environments. Additionally, the study focused only on one type of biological sample—human blood—and future research could explore how DNA degradation rates differ across various sample types, such as saliva, hair, or tissues.

Conclusion

This study highlights the significant role of environmental factors in DNA degradation, particularly the impact of UV radiation, temperature, and humidity. The findings emphasize the need for careful control of environmental conditions to preserve DNA integrity in forensic, archaeological, and biobanking applications. Minimizing UV exposure, controlling temperature, and reducing humidity are key strategies for enhancing DNA preservation and ensuring the reliability of genetic analyses. Future research should focus on expanding these findings to a wider range of biological samples and real-world environmental conditions to further refine DNA preservation protocols.

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