From the Lab to the Kitchen: A Critical Review of Low-Cost DNA Extraction Methods and the Quest for Truly Household-Based Protocols

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Abstract

Commercial DNA extraction kits are too expensive and scarce, hence affordable alternatives are needed. This is especially true in low-resource contexts. Despite recent advances using basic kitchen reagents like dish soap, salt, and vinegar, this review argues that a truly household-only protocol remains impractical. We examine low-cost hybrid methods that use some lab-grade chemicals and regular laboratory methods and critically evaluate the spectrum of intermediary low-cost solutions. We demonstrate that from certain simple animal tissues (e.g., fish mucus, blood). We show that these methods can achieve yields and purity levels suitable for basic PCR under certain conditions. Sequencing, standardization, repeatability, and validation remain difficult in complex systems. This analysis shows that researchers should shift from proof-of-concept studies to systematic creation, optimization, and validation of home-implementation approaches. Obtaining this molecular biology "holy grail" is essential for democratizing genetic tools in biology, worldwide education, and citizen research.

Keywords: DNA Extraction, Household Reagents, Cost-effective, Molecular Biology, Low-resource Settings.

Introduction

For laboratories with limited resources, Deoxyribonucleic Acid (DNA) extraction methods utilizing ordinary household reagents hold significant potential (Susantini et al., 2017; Talebi et al., 2021a). Recent study shows that extracting DNA from a range of biological materials is difficult and requires particular procedures. Despite producing a lot of DNAs, phenol-chloroform extraction is toxic, time-consuming, and difficult to obtain. Researchers want better, more accessible, and cheaper extraction solutions to tackle these obstacles. These technologies can

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synthesize high-quality DNA for molecular reactions like Polymerase Chain Reaction (PCR) (Sambrook & Russell, 2001; Waheed et al., 2024).

Extraction of DNA is the first and most important step in molecular biology as extraction of DNA from sample directly influences the success of applications of extract DNA such as PCR, genotyping, forensic analysis, disease diagnosis, biodiversity and sequencing (Aslam et al., 2025; Brodzka et al., 2025). However, in many research facilities, institutes and teaching laboratories in many developing countries the routine use of commercial extraction kits is restricted due to limited availability and cost (Helmy et al., 2016; Silva et al., 2023). Further, the developing countries have cold-chain dependency and requires specialized infrastructure and thus creating a gap between actual capacity and growing need for molecular tools in low income countries (Ullah et al., 2026).

In recent era, there is increasing attention for use of inexpensive, safer and locally available alternatives to conventional lab reagents. Household materials such as table salt, alcohol, detergents, baking soda, vinegar and plant derived enzymes are being tested for performing the functions of lysis, protein disruption stabilization of DNA and DNA precipitation in the place of conventional laboratory reagents (Talebi et al., 2021). These methods are important in science education, field-based studies and preliminary screening or areas, where achieving of low-cost extractions are important than purity of DNA. These methods are widely dependent on tissue type, extraction condition, reagent composition and intended applications (Talebi et al., 2021)..

Overall, such cheap solutions facilitate scientific approaches and access to biotechnology that are environmentally friendly. They are also listed in the UN Sustainable Development Goals (Aslam et al., 2026; Liao et al., 2025). Although the progress has been significant, the field does not have a household-based approach. Despite their uses, household-based extraction of DNA still requires critical evaluation before use as reliable substitutes of standard lab reagents (Susantini et al., 2017). Therefore, this review aims at critically examining this journey by explaining the same and enumerating the steps required in order to bridge this last gap.

Methodology

To achieve this study, we searched academic databases including Web of Science, PubMed, and Google Scholar to search through the published literature systematically for the period 1988–2025. We sought DNA extraction procedures of animal tissues that involve low cost, readily available, and non-toxic chemicals. Specific attention was given to those that could be easily replaced with items that you already have in your kitchen or house. The search keywords used were non-toxic DNA

extraction, house hold reagents, low-cost DNA extraction of animal tissue and DIY DNA extraction. One of the objectives of this work was the identification, classification, and comparison of these techniques with the established laboratory chemical procedures and commercial kits (Lenka et al 2025).

A Tiered Taxonomy of Low-Cost DNA Extraction Methods

In this era, numerous research works are carried out on cheap DNA collection and numerous ways. Others involve in-depth assessment whereas others only need a few lab items (Haripriya et al., 2025). In order to study this work and explain the primary conclusion, we provide a new taxonomical system where one can divide such approaches into three levels based on their resource requirements and cost:(1) Pure Kitchen, (2) Hybrid, and (3) Low-Cost Lab. The end goal of the field is a protocol that is completely within the "Pure Kitchen" tier. This classification provides us with a good thinking method regarding the trade-offs among accessibility, reproducibility and analytical performance as summarized in Table 1.

Table 1: A Tiered Taxonomy of Low-Cost DNA Extraction Protocols.

Tier	Definition	Key Reagents	Pros	Cons	Best Use Cases
Pure Kitchen	Uses only reagents and tools found in a typical household/kitchen or general store.	Dish soap, table salt, baking soda, vinegar, ethanol, meat tenderizer, and filter paper.	Ultra-low cost, maximum accessibility, safe, and no specialized storage, empowering for education/citizen science.	Lowest reproducibility, highly variable yield/purity, limited validation, and fails with complex tissues.	Basic education, citizen science, principle demonstration, and very limited fieldwork (soft tissues).
Hybrid	Uses mostly household reagents but requires 1-2 critical lab-grade chemicals for reliability.	Dish soap, salt, but also EDTA, Tris buffer, or Proteinase K.	Very low cost, good reliability, and a much higher success rate than pure kitchen.	Requires minimal lab inventory (balances, pH strips, access to 1-2 chemicals).	Advanced education, fieldwork with portable lab capability, robust citizen science, and some research.
Low-cost lab	Uses laboratory-formulated reagents but in simplified, open-source, or bulk-prepared protocols.	CTAB, Guanidinium Thiocyanate, Silica columns, SDS, Phenol-Chloroform.	High reliability, excellent yield/purity, validated for many applications.	Requires a full lab environment, chemical storage, and safety protocols.	All research contexts, diagnostics, sequencing, and work with difficult tissues (bone, FFPE).

Cost-Effective Protocols and Household Reagent Innovations

A significant amount of research demonstrates that inexpensive, in-house techniques can produce DNA comparable to that obtained from commercial kits. Figure 1 shows how everyday household chemicals like detergent, salt, vinegar, papain, baking soda, and ethanol work at each step of DNA isolation (Baldi & La Porta, 2020). We focus on the basic ideas

and the use of lab-grade parts to group these discoveries by theme and make them easier to read.

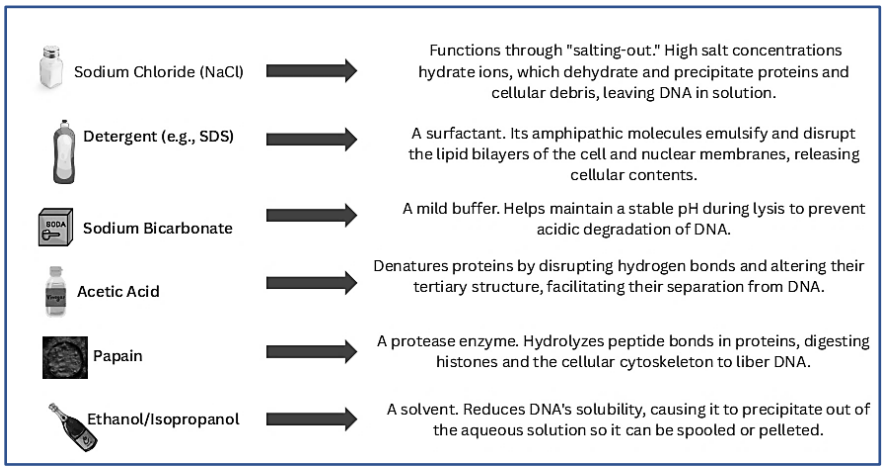

Figure 1: Common household reagents' biochemical roles in DNA extraction. The picture depicts how detergent, salt, vinegar (acetic acid), papain, baking soda (sodium bicarbonate), and ethanol work at each DNA isolation step.

Detergent-Based Lysis Methods

Sodium dodecyl sulfate (SDS) and other amphipathic molecules present in laundry powder and similar surfactants in dish soap are the building blocks of detergent-based lysis. These chemicals work by breaking down proteins and lipids into smaller pieces and releasing genomic DNA into the solution. This breaks down the lipid bilayer of the cell membrane and nuclear envelope. Bahl and Pfenninger (1996) showed that genomic DNA may be successfully retrieved from tiny tissue samples using laundry detergent. Home detergents have different amounts and types of surfactants, which makes their lysis efficiency uncertain and likely to induce DNA shearing. This is a big problem. For this reason, laboratory buffers are necessary for many powerful methods, such the MoLSC approach (Arseneau et al., 2017) and the high-throughput lysis that uses laundry powder with EDTA and Tris (Talebi et al., 2021b). One important job that household chemicals can't reliably do is stop DNases from breaking down DNA. EDTA binds to Mg^{2+} ions, and tris has the right pH for cell health and enzyme activity, if used.

Salt-Based and Precipitation Methods

The process of salting-out is used by salt-based methods to get 533 ± 84 ng/µL from meat samples (Yalçınkaya et al., 2017). Proteins and other biological detritus sink to the bottom of a container with high salt

ion concentrations because they attract water molecules. Still, DNA is soluble. This is followed by the extraction of DNA by the use of alcohol. This is a cheap and efficient process, but may produce unwanted compounds, such as polysaccharide and heme pigments. DNA is selectively bound to silica matrix by chaotropic salts in commercial kits. This attachment technique might wash away DNA contaminants. To consistently obtain high-purity results from complex tissues, Tris and EDTA must be used. Tris-HCl EDTA treats cow blood well.

Enzymatic Methods with Household Sources

The main obstacle to processing complex animal tissues (bone, muscle, organ) is the lack of a reliable protease found in home items. Papain and other well-known meat tenderizer proteases differ biochemically from laboratory standard proteinase K and have lower activity levels. Proteinase K is used for digestive methods and single-buffer lysis because it is a broad-spectrum serine protease that works even with denaturants like SDS (Trigodet et al., 2022). Papain, on the other hand, is a cysteine protease that has a specific pH range and narrow selectivity (Mohd Azmi et al., 2023) . All well-established DNA extraction methods require proteinase K for digestion. This is especially true for protein-rich tissues like bone and hair, which are hard to digest (Ghatak et al., 2013; Haarkötter et al., 2023; Marshall et al., 2014). Given this dependency, papain cannot be used as a "drop-in" Proteinase K alternative. The lack of a household enzyme with Proteinase K's stability and wide specificity may also hinder Pure Kitchen methods. Table 2 shows a summary of various cheap and easy-to-use DNA extraction methods from the literature.

Pure Kitchen Approach Based on Homegrown Ingredients

Some researchers have used natural materials, but most use laboratory compounds. The filter paper and salt-detergent method for fish mucus (Gui et al., 2022) is the most successful pure kitchen protocol, but it only works for targets with a lot of copies. The baking soda and vinegar method based on acid-base chemistry Miller et al. (1988) is also a novel method, but it is not that effective in controlling pH, which does not produce small variations.

The Hard Ceiling of Pure Kitchen Methods

Simple tissues can be done using pure kitchen methods but this is not feasible for case studies of more complex samples. This ceiling is generally made by two factors that are interconnected.

The Protease Problem

As previously mentioned, the lack of a household-sourced enzyme that breaks down complicated tissue matrices is a major concern. Papain, present in meat tenderizer, is commonly considered a substitute for laboratory-standard Proteinase K, although studies have shown that it is less effective and dependable (Eychner et al., 2015).

Table 2: Summary of Low-Cost and Household DNA Extraction Methods from the Literature.

Study	Protocol Tier	Key Reagents / Protocol Type	Tissue Types	Performance vs. Commercial Kits	Downstream Success	Approx. Cost per Sample
Gui et al. (2022)	Pure Kitchen	Filter paper, salt, detergent	fish mucus/blood	95% PCR success rate; not validated for sequencing	PCR (95%)	$0.02
Miller et al. (1988)	Pure Kitchen	Baking Soda and Vinegar	Human cells	Sufficient for basic PCR; low reproducibility	Basic PCR only	< $0.10
Yalçınkaya et al. (2017)	Hybrid	Salt-based extraction	Various animal tissues	Higher yield (533 ng/µL) than commercial kits (~200 ng/µL); slightly lower purity	PCR Successful	< $0.10
Talebi et al. (2021)	Hybrid	Laundry detergent + EDTA + Tris	Farm animal blood	20-30% higher yield, equivalent purity (A260/280 ~1.8) vs. Qiagen kits	PCR and other applications.	< $0.50
Peñafiel et al. (2019)	Hybrid	Simplified animal DNA protocol	Blood, muscle, skin	Comparable to commercial kits; works for Sanger sequencing	PCR & Sanger sequencing.	~$0.10
Buzan et al. (2020)	Low-cost Lab	Demineralization, silica	Wild ungulate bone	High-quality nuclear DNA.	Microsatellite analysis.	Microsatellite analysis.
Commercial Kit	N/A	Silica membrane, lab-grade buffers	Various	High yield, high purity, high reproducibility	PCR, qPCR, NGS.	$5.00 - $10.00

The Purification Problem

Common PCR inhibitors are difficult to remove using house protocols. Non-selective procedures include salt-alcohol precipitation. This method can co-precipitate DNA, heme, polyphenols, and polysaccharides (Haarkötter et al., 2023).On the other hand, the bind-wash-elute method used by commercial silica columns or magnetic beads selectively binds DNA when chaotropic salts are present (Boom et al., 1990) allowing contaminants to be washed away . Since there is no domestic counterpart to selective purification technology, Pure Kitchen methods often fail in downstream applications like quantitative PCR or next-generation sequencing. Figure 2 shows a general extraction workflow and points out where household reagents are not effective.

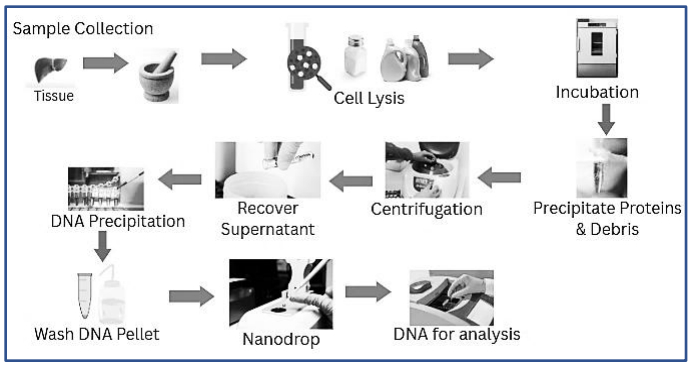

Figure 2: Generalized Extraction Workflow.

Application and Real-World Validation: Successes are Overwhelmingly Hybrid

A stringent examination of practical uses shows that hybrid and low-cost laboratory procedures can produce the most robust and scientifically challenging results, usually, compared to pure kitchen ones (Smith et al., 2023). This is regardless of the fact that low-cost processes have an influence. This tendency proves the categorization of the review and outlines the flaws of the approaches based on household-oriented approaches alone.

Pure Kitchen methods are in principle confined to mere demonstrations and non-invasive, focused sampling. As an example, Gui et al. (2022) developed a filter paper-based system for genetic screening of fish mucus, which contains much extracellular DNA. It is however not a suitable method in the case of complex tissues which would demand vigorous cellular lysis and purification.

Nevertheless, in cases of complex genetic studies that need DNA of complex tissues and the use of the technique requires reliability, hybrid methods are needed. Using lab-grade buffers, the method developed by Peñafiel et al. (2019), for Sanger sequencing in animal blood and muscle enables cost-effective disease identification in resource-constrained scenarios. This level of diagnostic reliability is not achievable with pure kitchen operations.

Even low-cost silica-based purification methods are needed for most challenging samples like damaged bone. Buzan et al. (2020) extracted high-quality nuclear DNA from wild ungulate bones for microsatellite analysis, a core technique in population genetics. This purpose requires silica's selective purification capacity, for which there is no household equivalent.

Thus, as OpenCell has shown, the way to democratization involves hybrid systems that mix inexpensive reagents with a low cost,

laboratory-grade components (Gupta et al., 2024). The most important research and diagnostic applications in the industry do not use Pure Kitchen processes, so the last gap must be closed to genuine household-based methodologies. Figure 3 shows a basic bar chart that compares the three primary types of procedures (Pure Kitchen, Hybrid, and Low-Cost Lab) based on how reliable, cheap, and complicated they are.

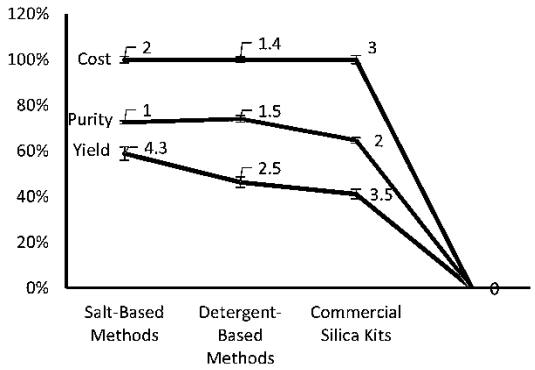

Figure 3: A simple bar chart comparing the three main categories of methods.

Limitations and Challenges: The Hurdles of Standardization and Scalability

While several biochemical barriers prohibit household-based DNA extraction, systemic validation, scalability, and standards issues must also be addressed. The intrinsic diversity of household products is one of the biggest impediments to consistency. A "Pure Kitchen" technique would be hard to standardize because dish soap companies have different surfactants and additives. The lack of precisely described reagents hinders reproducibility in controlled laboratory environments, where technique bias can cause large findings differences. This is because reagent absence might significantly alter results (Tourlousse et al., 2021). Second, these protocols have serious scalability and throughput issues Shamash et al. (2025) suggest that commercially available automated systems based on beads are superior for high-throughput processing in research and diagnostics than manual methods that involve a lot of labor. One of the main reasons lean and effective methods are sought for large-scale studies is because of this scalability limitation (Goudoudaki et al., 2025).

In conclusion, crucial validation and benchmarking remain issues. Users cannot properly define a methodology without comprehensive validation against laboratory-standard kits across a number of tissues and applications, such as qPCR and NGS. This prevents the methodology from being used for scientific study. Research has shown that even with

standardized kits, competent laboratories may extract different amounts of DNA (Burke et al., 2022). Therefore, diagnostic tests must be rigorously validated.

Discussion

This review indicates that the current issue in the democratization of DNA extraction is no longer whether low-cost recovery of amplifiable DNA is possible, but rather whether low-cost methods of DNA extraction can be made robust, repeatable, and generalizable beyond the laboratory environment. It is certainly true that Pure Kitchen protocols are useful as an educational outreach, citizen science, and even basic proof-of-concept tools, but their utility seems to be reduced significantly in complex, protein-rich, or inhibitor-laden tissues, which require more efficient lysis and purer purification (Sajali et al., 2018). This is inherently limited by two unsolved bottlenecks: the unavailability of a household-derived protease that has the stability and broad substrate specificity of Proteinase K and the unavailability of a domestic analog to selective silica- or bead-based purification systems that can eliminate PCR inhibitors without damaging DNA (Eychner et al., 2015; Boom et al., 1990) Conversely, hybrid protocols are always the most feasible and scientifically justified middle ground, with the affordability and accessibility of household-compatible reagents being balanced by a minimal number of laboratory-grade components that significantly enhance the reliability, purity, and downstream analytical success (Peñafiel et al., 2019; Talebi et al., 2021; Gupta et al., 2024). Collectively, these results suggest that the urgent need of the field, instead of the untimely advancement of the entirely household-based workflows, is the strict benchmarking, standardization, and cross-context validation of the hybrid solutions as a stepping stone towards the real accessibility of molecular biology.

A household protocol roadmap for the future

We need to find a way to extract DNA at home if we want biotechnology to be common to people. This review paper contends that the discipline needs to shift from discrete proof-of-concept research to a coordinated, methodical effort in standardization and validation, even though considerable progress has been made with low-cost and hybrid procedures. The following is the concrete roadmap that we suggest to reach this objective.

The Benchmarking Project

A detailed study of the most effective home goods (including various brands of dish soap, salt, and alcohol) to create reliable, easy-to-replicate recipes.

The Tissue-Specific Initiative

By developing and testing a single, powerful Pure Kitchen technique on strawberry or chicken breast (muscle), this crowdsourcing effort aims to set a standard.

The Enzyme Replacement Challenge

A study to find and improve an optimized, efficient, and easily accessible house protease to solve complex tissues' bottleneck.

The Standard of validation

Minimum validation requirements (such as yield, purity, and PCR/sequencing success rate) that a method must fulfill in order to be a reliable Household Protocol. This well-defined strategy will help researchers turn unique kitchen protocols into universal tools. We'll get closer to making genetic research available to everyone (Rasheed et al., 2025; Ullah et al., 2025).

Conclusion

This review covers the low-cost DNA extraction method for improving access to molecular biology in limited resources. Household regents can support basic DNA extraction particularly for simple tissues and demonstrations in educational settings. However, fully pure kitchen-based DNA extraction protocol remains limited due to lower reproducibility, weak proteolytic capacity, variable reagent composition and insufficient purification. Currently, hybrids methods combing both house-hold reagents and few essential laboratory level reagents offer most practical balance for affordable extraction. Hence, future work should focus on systematic benchmarking, tissue-specific optimization and development of accessible substitute for laboratory reagents.

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