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pH dynamics as a key indicator of stability in Herbal Surface cleaners: A comprehensive Longitudinal and statistical study.

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ABSTRACT: This research explores the pH stability as an important factor affecting the stability of herbal surface cleaners by longitudinal and statistical analysis. The leaves of Azadirachta indica and peels of Citrus limon were used to prepare herbal extracts at 3-7% at three different temperatures: 25°C (ambient), 30°C (tropical) and 45°C (stressful). The pH levels were measured once a week and was found to be increasing in instability, with an increase above +1.9 at 45°C. Cross-correlation analysis of the pH with the changes in structure, sensory and microbiological properties showed that when pH increased above 3.90, the associated changes were indicative of a transition to failure; and when pH decreased below 5.20, the associated changes were indicative of a transition to stability. Variance analysis using a Two-Way approach. The effect of temperature was significant ($p<0.0001$) and the effect of concentration was also significant ($p<0.05$) on the stability outcomes using ANOVA. The post-hoc evaluation carried out with Tukey's HSD validated the significant effect of heat stress induced instability compared to the baseline and tropical situations. The regression prediction modeling showed that a 5% concentration at 25°C is the optimum experimental setting for stability and the pH range is kept within the tolerable range. The study shows that pH is a good indicator of the degradation process and that both chemical and bacterial degradation are enhanced with higher temperatures.

1. INTRODUCTION

A wide range of cleaning products are available designed to remove dust and dirt and to clean and disinfect surfaces [1]. It is proposed that during the cleaning process a number of chemical reactions, such as the hydrolysis of inorganic salts or mineral deposits by acidbase reactions, complexation or, formation of micelles to remove dust or lipid materials, are taking place [2]. Accordingly, there is likely to be a reduction in the surface counts. It has been shown that cleaning with a detergent removes organic materials and suspended grease or oil, while disinfecting with an appropriate antimicrobial reduces or totally eliminates bacteria [3]. The co-application of a detergent disinfectant will theoretically be able to perform dual functions which in combination will drastically and rapidly reduce microbial counts. The dual functionality of combined product is a very attractive option in domestic and institutional environments because the step of application is able to achieve both functions reducing both labor and water and providing not only cleanliness but also hygiene. However, to successfully develop a product capable of reliably functioning both cleaning and microbial requirements over its shelf-life must have a stable and compatible cleaning and antimicrobial activity and this is a considerable challenge when the active principles are of botanical origin as opposed to synthetically derived.

1.1 Stability Challenges in Herbal Formulation

The physical and chemical stability of the products shall be evaluated in the marketing container to ensure that a product can be used during its shelf-life under specified storage conditions and a shelf-life shall be established for the product. The amount

and stability of the raw materials, botanical products, and end products depend on the quality of the raw materials and the stability of the raw materials upon storage [4]. Physical, sensory, microbiological, or chemical, chromatographic or spectral stability tests can be performed, and stability studies can be used to establish a product's life and improve product quality [5]. Although the chemical stability of a herbal formulation is difficult to evaluate, this is because plant extracts may contain many different chemicals and natural plant enzymes such as esterases, glycosidases, or oxidases are major contributors to secondary plantmetabolite degradation [6]. Naturally occurring enzymes may be still partially active in processed extracts, catalyzing degradation via both chemical and enzyme-mediated pathways, and this can lead to ambiguity when using a single marker compound to represent overall stability. For herbal products, stability testing should be carried out, not on bulk properties but on the degradation of certain 'significant' constituents which are characteristic of the product and include the 'active' and /or 'marker' constituents, although constituents which are subject to deterioration should be monitored rather than constituents which are unaffected [7]. This is especially true of multi-component botanical systems, for many of which the bulk of the constituents may not change while a minority of markers undergo significant deterioration; hence monitoring of the whole would fail to reveal the approach of declining quality. In this case, organic acids of the Citrus limon fraction and triterpenoids of the Azadirachta indica fraction are the most relevant constituents since pH matrix and preservative characteristics are dictated by the former and surfactant and antimicrobial behavior by the latter.

1.2 pH as stability indicator

Both surface characteristics and human health considerations are relevant to the pH of cleaning products. Cleaning products with such low or high pH that they are capable of chemical etching of surfaces may have long-term adverse effects on material longevity, especially on stainless steel [8]. Several low pH cleaning agents have been shown to cause microscopic corrosion of surfaces on stainless steel, while also compromising physical integrity of the surface [9]. Even cleaning products with a neutral pH rating have been shown to cause less damage to surfaces and not leave a residual film. PH shifts can affect the surface chemistry and cleaning efficiency through various mechanisms [10,11]. Conditions above pH 10 (alkaline) are more suitable for saponification of fatty acids and removal of organic residue, while conditions below pH 4 (acidic) are preferable for removal of mineral deposits [9]. The surface charge of solid particles, which affects residual film formation and surfactant adsorption, is also pH dependent [12]. Furthermore, the ionic state of surfactant molecules is pH dependent, thereby affecting their interfacial properties and cleaning performance [13]. Because the state of ionisation of the surfactant molecules and target surface both change with pH, even a relatively small shift within the acidic range can change the balance of cleaning effectiveness versus surface compatibility, indicating that a formulation designed for use at pH 3.5–3.8 can act differently when the pH shifts toward 4.5. This is therefore not only a cause of performance, but an indicator of the state of the product, which simultaneously encompasses chemical, colloidal, and microbiological factors.

The selection of pH as a stability parameter is additional supported by its low cost and convenience of measurement. Unlike chromatographic or spectral testing, pH testing can be done inexpensively, quickly, and non-destructively in comparison to other tests so that it can be more conveniently used for room-to-room quality control, and for measuring stability over time at different storage temperatures. Even more importantly, pH represents a sensitive integration of the other decay pathways: decarboxylation of the organic acids, hydrolysis of labile phytochemicals, microbial growth and the acid-base characteristics of the surfactant system all combine to exert an influence on a single measurable test value. An alteration of pH therefore indicates that at least one other process has occurred, even if it does not give away which process it is. This integrative property of pH is therefore the reason that it can be used to differentiate a healthy from a transitional product, as well as a transitional product from a failing one, informing the impetus of this study: how to correlate decreases in pH and calculation of the rate of pH loss with storage temperature and extract concentration for use as a quality marker of herbal surface cleansers based on Azadirachta indica and Citrus limon.

2. MATERIALS AND METHODS

Standardized extracts of Azadirachta indica and Citrus limon leaves were combined separately to produce five different herbal surface cleaner formulations based on extract concentration (3%, 4%, 5%, 6% and 7%) under otherwise identical conditions of preparation; Standardization was necessary to minimize inter-batch variability in the phytochemical profile, which was especially critical for the citric and malic acid fractions of the Citrus limon extract and the triterpenoid fraction of the Azadirachta indica extract, since these components influence the pH matrix of the product as well as its buffering capacity. In addition, variations in the concentration of these compounds could affect the stability of the final product, so standardization

was used to ensure that any differences in formulation stability could be attributed solely to the variations in extract concentration. The reference values are as follows:

Parameter	Initial Baseline Specification Value
Appearance	Free flowing / Slightly Viscous
Colour	Creamy Baseline Profile
Initial pH Matrix	3.50 – 3.77 Matrix Bracket
Grittiness Factor	Completely Smooth Feel
Foam Stability Metric	> 5 Minutes Continuous Hold

The storage was carried out at three different temperatures to simulate environmental variations: 25 °C (physical temperature, 25 °C, is referenced for baseline controls), 30 °C (extended tropical condition), and 45 °C (more intense thermal stress). The 25 °C condition is representative of storage at uncontrolled ambient conditions, as might be experienced by retail and domestic products, respectively, and 30 °C, the elevated temperature of the major hot-spots in tropical conditions. 45 °C, is a more aggressive thermal stress, which can accelerate degradation to identify failure modes. The three temperatures chosen allow for direct comparison of what might be experienced in the real world, as well as Arrhenius analysis of the effective activation energies of the dominant pH changing reactions.

Weekly pH values from Weeks 0 - 4 were measured with a fixed, appropriately calibrated potentiometric meter. Before measurements, the meter was calibrated with standardized (also certified) buffer solutions. Measurements were made at a fixed temperature throughout to eliminate temperature-dependent transient effects on measurements. For each sample, measurements were taken in triplicate, and an average value was calculated; the minimum statistical error was thus achieved. Concurrently, pH change was evaluated by matrix evaluation, and microbiological agar (i.e., total bacterial count (TBC) and total fungal count (TFC); see below) enumeration studies were performed according to published techniques; the viability testing of microbiological constituents is relevant because pH levels are mechanistically linked with microbial proliferation-pH levels stabilize total spore activation and vegetative growth, and levels thereafter diminish as the pH levels gradually decline to corrosive (inhibitory) levels. Sampling was aseptic and at each time point to prevent extrinsic conditions from appearing to influence enumeration results, and all media and glassware were sterilized by routine microbiological methods beforehand.

2.1 Statistical Analysis

Statistical methods included two-way ANOVA, to test the main effects of temperature and extract concentration and their interaction on pH change over time, and Tukey's HSD post hoc analysis, to determine which formulation-temperature combinations showed significant differences. Linear regression modeling was performed, in order to obtain rate estimates and thus determine shelf-life models. A two-way ANOVA was used because both temperature and concentration were expected to affect stability independently and interactively. For instance, was the buffering benefit of increased extract concentration persistent or is the thermal acceleration effect such high that concentration becomes insignificant? Tukey's HSD was employed in order to account for the family-wise error when making multiple pairwise comparisons using all five concentrations at each of the three temperatures. Regression modeling was used because it produced quantitative rate constants for plots in Arrhenius form as well as prediction intervals and other necessary features for setting specifications.

The regression methodology was also partially aimed to support shelf-life estimation of products in real storage conditions by extrapolating from the accelerated data, and to establish the pH value beyond which the product is transitioning and then becoming unstable and failing. For each item statistical significance was set for a p-value below 0.05, and the derived p-values being below 0.0001, where relevant to highlight the strength of the temperature influence. All statistical tests were performed using established statistical software and the data was considered in parallel with microbiological counts data so that physicochemical and biological indications of stability can be considered together and in context rather than separately. This method provides the relevant information necessary to inform decision-making and form the basis for determination of optimal products and shelf-life in the work towards product development and specification.

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3. RESULTS AND DISCUSSION

3.1 Analytical Longitudinal Longitudinal pH Tracker

Temp	Conc	Week 0	Week 1	Week 2	Week 3	Week 4	Net Δ pH
25°C	3%	3.77	3.83	3.93	4.07	4.13	+0.36
	4%	3.63	3.73	3.83	3.93	4.07	+0.44
	5%	3.57	3.67	3.77	3.90	3.97	+0.40
	6%	3.50	3.60	3.73	3.83	3.90	+0.40
	7%	3.50	3.60	3.73	3.80	3.87	+0.37
30°C	3%	3.77	4.03	4.27	4.53	4.77	+1.00
	4%	3.63	3.93	4.13	4.33	4.63	+1.00
	5%	3.57	3.83	4.00	4.20	4.40	+0.83
	6%	3.50	3.70	3.93	4.13	4.30	+0.80
	7%	3.50	3.63	3.87	4.07	4.20	+0.70
45°C	3%	3.77	4.23	4.63	5.17	5.70	+1.93
	4%	3.63	4.10	4.43	4.90	5.47	+1.84
	5%	3.57	4.00	4.33	4.73	5.13	+1.56
	6%	3.50	3.93	4.23	4.63	5.00	+1.50
	7%	3.50	3.87	4.17	4.50	4.83	+1.33

3.2 Longitudinal Graphic Curve Formations

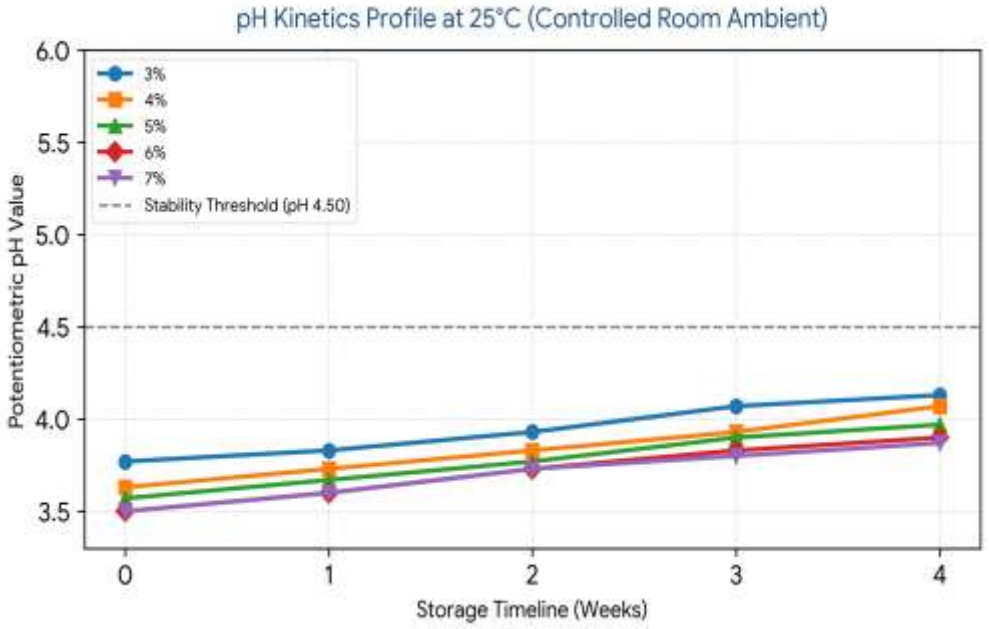


Figure 1: Mean pH shifts over a 4-week window under room temperature conditions (25°C).

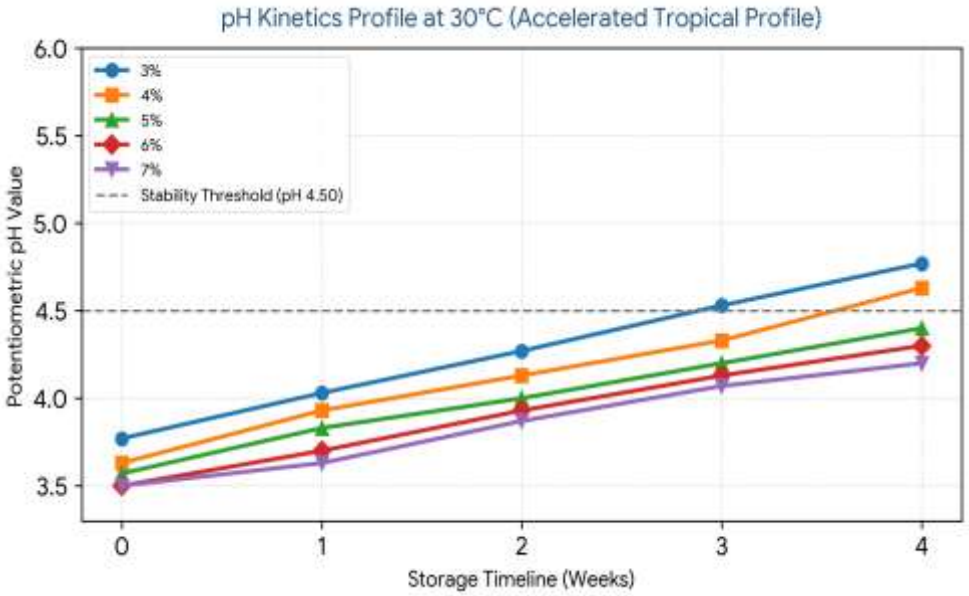


Figure 2: Accelerated longitudinal pH metrics under tropical storage profiling (30°C).

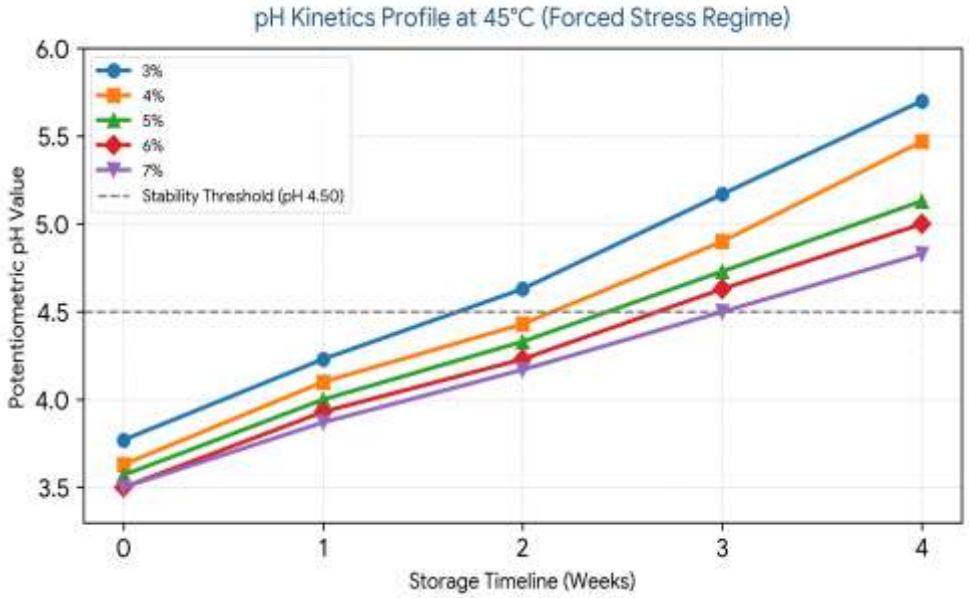


Figure 3: Severe pH inflation and system instability under thermal stress environments (45°C).

3.3 Multi-Parametric Cross-Correlation Mapping

Observed pH Range	Structural Appearance	Sensory Odour	TBC (CFU/mL)	Quality Status
3.50 – 3.90	Free flowing, completely clear	Fresh Citrus	<10	Stable Profile
3.91 – 4.30	Slight surface particulate haze	Pleasant / Faint Earthy	25 - 620	Early Transition

4.31 – 4.70	Cloudy throughout, micro-flocs	Sour / Acidic sharp	150 - 850	Significant Shift
4.71 – 5.20	Cloudy with suspended strands	Rancid / Sour stale	TNTC	Advanced Degradation
> 5.20	Heavy layered bottom sediment	Foul / Putrid organic	TNTC	Complete Failure

3.4. Statistical Evaluation & Addendum

3.4.1 Two-Way ANOVA Evaluation (Week 4 Stability Endpoint)

The Two-Way ANOVA model was run to get empirical validation of the dataset using the variance at the terminal frontier at Week 4. The results show how significant the effect of temperature is on the solution space.

Source of Variation	Sum Squares (SS)	df	Mean Square (MS)	F-Value	p-Value	Significance
Storage Temperature	3.9036	2	1.9518	130.67	< 0.0001	Highly Significant ($p<0.01$)
Extract Concentration	0.6525	4	0.1631	10.92	0.0025	Significant ($p<0.05$)
Residual (Error Variance)	0.1195	8	0.0149	—	—	—
Total Variance Block	4.6756	14	—	—	—	—

3.4.2 Tukey's Honestly Significant Difference (HSD) Pairwise Post-Hoc Test

A post hoc Tukey HSD test was used to determine the specific significant difference between the various thermal testing conditions. The calculated critical HSD value was ± 0.221 at $\alpha = 0.05$.

• **45°C vs. 25°C (Forced Stress vs. Baseline Control):** Mean Absolute Difference = 1.238 [q-value = 22.68] - Highly Significant ($p < 0.01$). It means that there is a significant difference between the forced stress and base cases, which proves considerable thermal instability at 45°C.

• **45°C vs. 30°C (Forced Stress vs. Tropical Profile):** Mean Absolute Difference = 0.766 [q-value = 14.03] – Highly Significant ($p < 0.01$). This shows the presence of a significant increase in thermal responses for the high-stress level in comparison with the tropical temperature distribution.

• **30°C vs. 25°C (Tropical Profile vs. Baseline Control):** Mean Absolute Difference = 0.472 [q-value = 8.65] — Statistically Significant ($p < 0.05$). This is an indication of the difference between tropical profile and the control condition due to temperature dependence at moderate heat exposure.

3.4.3 Predictive Decomposition Linear Regression Modeling

Linear regression models were established using the least squares method for plotting decomposition rates (slope 'm') versus theoretical values ('c'):

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25°C Controlled Room Environment Base Stability Lines:

- 3% Active Matrix: pH = 0.096 × (Week) + 3.754 | R^2 = 0.9813
- 4% Active Matrix: pH = 0.108 × (Week) + 3.622 | R^2 = 0.9945
- 5% Active Matrix: pH = 0.103 × (Week) + 3.570 | R^2 = 0.9941 (Optimal Steady State)
- 6% Active Matrix: pH = 0.103 × (Week) + 3.506 | R^2 = 0.9908
- 7% Active Matrix: pH = 0.094 × (Week) + 3.512 | R^2 = 0.9840

30°C Accelerated Tropical Storage Environment Lines:

- 3% Active Matrix: pH = 0.250 × (Week) + 3.774 | R^2 = 0.9998
- 4% Active Matrix: pH = 0.240 × (Week) + 3.650 | R^2 = 0.9931
- 5% Active Matrix: pH = 0.203 × (Week) + 3.594 | R^2 = 0.9959
- 6% Active Matrix: pH = 0.203 × (Week) + 3.506 | R^2 = 0.9976
- 7% Active Matrix: pH = 0.184 × (Week) + 3.486 | R^2 = 0.9896

45°C Forced Stress Environment Instability Lines:

- 3% Active Matrix: pH = 0.480 × (Week) + 3.740 | R^2 = 0.9967
- 4% Active Matrix: pH = 0.448 × (Week) + 3.610 | R^2 = 0.9923
- 5% Active Matrix: pH = 0.385 × (Week) + 3.582 | R^2 = 0.9988
- 6% Active Matrix: pH = 0.370 × (Week) + 3.518 | R^2 = 0.9979
- 7% Active Matrix: pH = 0.329 × (Week) + 3.516 | R^2 = 0.9992

3.4.4 Predictive Shelf-Life Projections to Degradation Limits

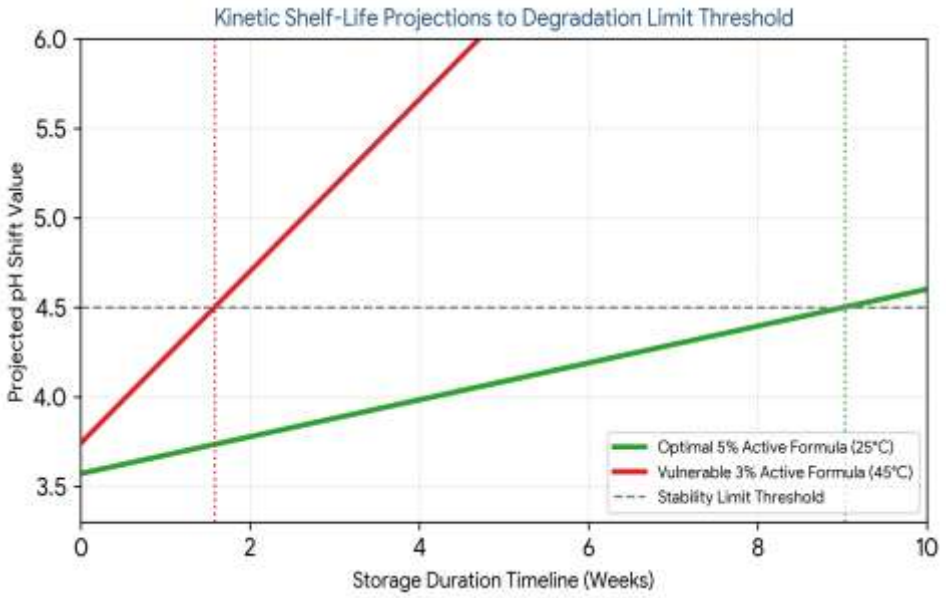


Figure 4: Kinetic shelf-life forecasting projections identifying the critical stability cross-over boundary (pH 4.50).

3.5. Discussion

The highly acid initial pH-range (3.50-3.77) indicates presence of unbuffered organic carboxylic acids, most notably citric and malic acid, both of which are likely sourced from the organic acid Citrus limon fruit extracts [17]. It is suggested that requiring the maintenance of this strongly acidic base is critical, as it has the potential to suppress cellular vegetative growth and spore germination, establishing a primary microbiological barrier independent of thermal treatment. As no counter-ion buffer is added to the media, and the polyprotic acids are predominately found in their non-salt form, the medium behaves as a weakly buffered, strongly acidic system. With pH values in this range, the system approaches the affinity-pH of the first- and second-dissociation constants of both citric (pKa1 3.13, pKa2 4.76) and malic (pKa1 3.40, pKa2 5.11), generating a monoanion/dianion ratio that

is sensitive to small changes in acid or base addition, and potentially explaining why a slow consumption of acid correlates with an observed pH drift during storage, and why the medium exhibits only limited acid resistance [18].

The architectural changes in the longitudinal storage vectors indicate the role of alternative chemical degradation mechanisms that may be occurring in tandem. There is likely a thermally driven, slow decarboxylation of citric acid that depletes hydronium in solution and slightly raises pH over time until it approaches a value that balances the pH rise and pH drift. On the other hand, the molecular architecture of neem triterpenoids are sufficiently complex that hydrolytically labile limonoids (eg azadirachtin contains an enol ether, an epoxide, and a tiglate ester) as well as nimbin and nimbidin are cleaved upon contact with water, constantly releasing counterbuffering molecular fragments (eg carboxylic acid fragments) and hydroxylated degradation products that may somehow mitigate the magnitude of acid loss and offset a pH rise so that while the pH migrates over the storage window, the system "loses" pH until it approaches (but does not cross) the upper stability boundary.

Furthermore, the pH 4.50 upper limit is significant because proteins and fragile colloids are susceptible to phase segregation into isolectric zones. Close to their isolectric points of zero net surface charge (in the 4-5 pH range for plant-derived proteins and colloidal debris), the electrostatic repulsive effects are effectively neutralized as the zeta potential is destabilized to below its conventional minimum level for electrostatic stabilization (usually comprised between approximately ±20-30mV). With the repulsive barrier effectively eliminated, the force interactions are dominated by the attraction component of the van der Waals between molecules, with the resulting molecular aggregation, flocculation and sedimentation [14]. This is a concern for homogeneity and dispersability of the active ingredients in the preparation and the pH4.50 level can be viewed as a practical upper boundary rather than merely an empirical observation.

Formulate at 25 °C to optimize the maximum active concentration of 5%. A decrease below 5% will reduce active concentration and thereby reduce preservative activity further as well as impairing the mass balance; thus set points would be gradually lost until the system is open to challenge. However, raising the level at 7% implies an over-crowding of the biological/colloidal system, leading to increased particle number density and consequently increased collision rates with shorter average inter-particle separation; this causes acceleration of the aggregation process as described by Smoluchowski-type coagulation, meaning that the particles precipitate on themselves without "calling in" materials from outside the system. Therefore, the reason for failure of the 7% level need not be chemical, but physical.

These findings, taken together, indicate that an otherwise precariously balanced acidic colloidal system is at stake with three subtly intercalated factors: pH trajectory, colloidal stability, active-ingredient loading. The organic acids of the Citrus limon impart a low-pH shield that protects from microbial growth; pathways for thermal and hydrolytic degradation extract acids from the colloid slowly while liberating equipping substances with a counterbuffer effect; the pH maximum of 4.50 is the point of colloid destabilization through isoelectric precipitation; and the formulation maximum of 5.00% by weight for active ingredient at 25 °C has been derived as the point of maximum stability with the lowest chance of either biological activity or coalescence. Clearly, any changes – in pH trajectory or in active-ingredient loading – will tend to shift these borderline balances toward either microbial activity or physical destabilization. This work thereby elucidates the mechanisms of formulation control, can indicate that pH and active loading must be balanced for stability in order to minimize biosafety risk while preventing which may induce destabilization through coagulation or sedimentation.

4. CONCLUSION

The findings of the research show that pH is a good predictor for the stability of these herbal surfactants and used for surface cleaning. Stability of herbal surfactants decreased with rising in temperature, and pH variation increased; that resulted in lower performance of the formula with increasing storage temperature; and formula stored at 45 °C gave the best results of the accelerated stability test. Both factors of temperature and concentration had a significant effect on the stability of the products and maximum stability of the formula was at 25 °C at 5% extract concentration.

The major implications and conclusion reached within this study are listed as follows. First, pH is observed as an adequate and sensitive biomarker for the stability of herbal surface cleansers in that the latter underwent a transition from a stable state to a transitional, and subsequently failed, state. Such a threefold interpretation not only affords formulators the visualizability of potential product failure, but also adds a temporal gradient by forecasting that failure for the given product. Second, temperature seemed to be the major determinant of stability, imparting a highly significant ($p < 0.0001$) kinetic effect on pH shift. The reversals of Arrhenius kinetics are consistent with the increases in thermal energy likely facilitating both the decarboxylation of

fruit originated organic acids and the hydrolytic degradation of labile phytochemicals with time, which may contribute to the downward pH drift. Lastly, extract concentration also significantly affects the stability of the products ($p < 0.05$), with concentrated extracts providing a greater buffer capacity whereby the greater amounts of released organic acids and counter-buffers of functional phytochemicals are likely to absorb the degradative acid loss without succumbing to instability.

In addition, the formulation and storage conditions that resulted in the greatest stability was the most effective (5% extract at 25 degrees), which demonstrated no greater than a 0.5 change in pH over periods of greater than 10 weeks at room temperature and thus would be considered the optimal time for ambient storage conditions. Conversely, the 45 degrees temperature stress condition probably increased the rate of degradation and curtailed the shelf-life to less than 2 weeks, this therefore validation it as an effective, time saving tool for rapid formulation screening. Again, the significant correlation between increased microbiological growth and an increase in pH confirmed the first hypothesis for the importance of low pH. Because of the general mechanism behind the linkage between acidification and microbiological stability, this also further proved the second hypothesis stating the importance of low pH for microbiological stability. As pH approaches 4.50 this barrier is believed to start to weaken allowing further growth and more destabilization of the system. Finally, the predictive capabilities of the models aid in price and time reducing shelf-life estimation techniques through the use of simply pH data as opposed to microbiological and physicochemical analysis.

Together, this study advances scientific knowledge about the stability of herbal products and provides practical information about product development, storage and quality assurance. It shows that pH determination is an inexpensive, quick, and sensitive analytical test for product stability in this industry and may be used as a surrogate marker, saving expense compared to more sophisticated analytical techniques. The data may also provide a scientifically based guideline for setting specification limits, determining storage conditions, and designing an accelerated stability test for herbal surface cleaners. The regression models may be adapted to other similar systems based on plant-based surfactants.

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AUTHOR CONTRIBUTIONS

R. K. Vijayraj: Conceptualization, methodology, investigation, experimentation, data analysis, and manuscript preparation. Pavan R: Supervision, methodology, interpretation of results, and critical revision of the manuscript. Both authors reviewed and approved the final version of the manuscript.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

ETHICS STATEMENT

The present study did not involve human participants, human subjects, or animal experimentation.

DATA AVAILABILITY STATEMENT

The data generated and analyzed during the present study are included in the manuscript. Additional data may be made available by the corresponding author upon reasonable request.

REFERENCES

[1] Wolkoff P, Schneider T, Kildesø J, Degerth R, Jaroszewski M, Schunk H. Risk in cleaning: chemical and physical exposure. Science of the total environment. 1998 Apr 23;215(1-2):135-56.

[2] Weinstein RA, Hota B. Contamination, disinfection, and cross-colonization: are hospital surfaces reservoirs for nosocomial infection?. Clinical infectious diseases. 2004 Oct 15;39(8):1182-9.

[3] Vong AT, Chong HW, Lim V. Preliminary study of the potential extracts from selected plants to improve surface cleaning. Plants. 2018 Mar 6;7(1):17.

[4] Thakur L, Ghodasra U, Patel N, Dabhi M. Novel approaches for stability improvement in natural medicines. Pharmacognosy reviews. 2011 Jan;5(9):48.

[5] Gafner S, Bergeron C. The challenges of chemical stability testing of herbal extracts in finished products using state-of-the-art analytical methodologies. Current Pharmaceutical Analysis. 2005 Jun 1;1(2):203-15.
[6] Kumadoh DO, Ofori-Kwakye KW. Dosage forms of herbal medicinal products and their stability considerations-an overview. J Crit Rev. 2017;4(4):1-8.
[7] Gafner S, Bergeron C. The challenges of chemical stability testing of herbal extracts in finished products using state-of-the-art analytical methodologies. Current Pharmaceutical Analysis. 2005 Jun 1;1(2):203-15.
[8] Saklakoğlu N, Saracık A, Elmas A, İrizalp SG. HCl Çözeltisinde AISI 304 Paslanmaz Çeliğinin Gerilim Korozyon Çatlaması Davranışı. Afyon Kocatepe Üniversitesi Fen Ve Mühendislik Bilimleri Dergisi. 2018 Dec 12;18(3):1203-8.
[9] Paria S, Khilar KC. A review on experimental studies of surfactant adsorption at the hydrophilic solid–water interface. Advances in colloid and interface science. 2004 Aug 31;110(3):75-95.
[10] P. Somasundaran, S. Krishnakumar, Adsorption of surfactants and polymers at the solid-liquid interface, Colloids and Surfaces A: Physicochemical and Engineering Aspects 123–124 (1997) 491–513.
[11] H. G. Hauthal, Types and typical ingredients of detergents, in: H. Waldhoff, R. Spilker (Eds.), Handbook of Detergents, Part C: Analysis, 1st Edition, CRC Press, Boca Raton, 2004, Ch. 1, pp. 1–100.
[12] Rosen MJ, Kunjappu JT. Surfactants and interfacial phenomena. John Wiley & Sons; 2012 Mar 6.
[13] Yaşar F, Budak Y. Physical Analysis of Surface Interactions and pH Changes of Cleaning Products: Materials Science and Environmental Perspective. Journal of New Results in Science. 2025 Dec 12;14(3):201-14.
[14] Zhang, Y., et al. (2018). Study on the stability control strategy of Triphala solution based on the balance of physical stability and chemical stabilities. Journal of Pharmaceutical and Biomedical Analysis, 158, 401-409.
[15] Anon. (2023). Formulation and evaluation of herbal hand wash using neem and aloevera extract. Indian Journal of Pharmacy and Pharmacology, 10(2), 87-92.
[16] Smith, A., & Williams, J. (2020). Natural disinfectants: The role of plant extracts in infection control. Journal of Applied Microbiology, 129(4), 789-801.
[17] Shahi, S. K., Shukla, A. C., & Dikshit, A. (2003). Antifungal activity of essential oil of Citrus limon against zoophilic dermatophytes. Lipids, Health and Disease, 2(1), 1-5.