SKIN

ORIGINAL RESEARCH

Enhancing Patient Compliance for Usage of Laundry Detergents Free of Dyes and Perfumes: Potential Impact of Better Cleaning Performance

Mary B. Johnson[1], C. Elaine Cella[1], Amanda Pessler[1], Dan B. Dillard[1], Andy Sullivan[1]

[1]The Procter & Gamble Company, Cincinnati, OH

ABSTRACT

Sensitive skin, an often self-reported condition, is characterized by an unpleasant sensory experience to a variety of consumer products. Certain ingredients in consumer products, such fragrances and dyes, are believed to exacerbate skin sensitivities. Due to an increased prevalence of people reporting sensitive skin, a variety of consumer products are formulated for people with this condition. A segment of commercially marketed laundry detergents, commonly known as free detergents, have been formulated without dyes and perfumes to accommodate skin sensitivities. In the US and Canada respectively, 80% and 97% of dermatologist recommend the use of free detergents for their patients with sensitive skin. However, consumers have expressed dissatisfaction with free detergents, with 39% reporting they are not satisfied with their free detergent's cleaning performance. When people switch from the leading free laundry detergent, they will switch to a non-free detergent 60% of the time, going against dermatologist recommendations and potentially further aggravating their skin sensitivities. A survey of US households with sensitive skin showed that 98.8% said that they would be more likely to consistently use a detergent that cleans better. Herein are reported data showing Tide Pods Free & Gentle outperformed other free detergents in cleaning across a wide variety of laundry stains and in SEM visual analysis of soil residues on fibers. It is postulated that the better cleaning detergent may help drive patient compliance with dermatologist recommendations for usage of a free detergent for their patients with sensitive skin.

BACKGROUND

Laundry Detergent Formulations and Sensitive Skin

Sensitive skin is often identified through unpleasant sensory reactions to consumer products such as cosmetics, soaps, toiletries, and laundry detergents after contact with the skin.[1] Epidemiological studies highlight the increasing prevalence of sensitive skin. Recent surveys demonstrate the prevalence of sensitive skin, with 44.6% of respondents reporting "sensitive" or "very sensitive" skin.[2] Some investigations report 69% of women in the United States as having sensitive skin.[3] Despite a lack of robust diagnostic tests, sensitive skin is largely recognized as a genuine dermatological condition.

Ingredients such as dyes and perfumes are frequently reported triggers of sensitive skin. Some dyes and perfumes have been shown to be skin sensitizers, capable of eliciting a response in skin over time.[4] Clinical studies have suggested that residual detergent on clothing can react with skin on an irritant basis.[5]

Several commercially available laundry detergents designed for sensitive skin are formulated without fragrances and dyes; these detergents are typically referred to as “free detergents”. While laundry detergents have been associated with sensitive skin, there is no present link between laundry detergents and other skin conditions such as atopic dermatitis.[6] Because it is believed that certain ingredients in traditional detergent formulations can aggravate sensitive skin, 80% and 97% of dermatologist in the US and Canada respectively, recommend the use of free detergents for their patients with sensitive skin.[7]

In addition to formulating free detergents without fragrances and dyes, other ingredients are carefully screened so that detergents can remain mild on skin while providing cleaning performance. Surfactants are major components of detergents and highly effective in removing dirt and soils in laundry. The chemical properties of different surfactants play a role in their cleaning performance and their skin irritation potential.[8,9] Surfactants can bind to keratin on the skin, causing protein denaturation. This leads to damage of the cell membrane, causing adverse skin responses such as redness, itchiness and irritation.[10] Advanced detergent formulation with different surfactants can impart significant cleaning performance while remaining mild on skin.[11]

For further cleaning performance, enzymes are added to laundry detergents to assist in breaking down the chemical bonds of stains and odor-causing molecules. Enzymes will speed up the natural process of stain decomposition, particularly with biological contaminants.[12] Enzyme-containing laundry products have an extensive history of safe use, and recent studies have determined that concentrations of enzymes in detergents do not cause adverse skin events.[13]

Special consideration is taken when formulating laundry detergents to ensure they are gentle on skin; detergents that clean well are sometimes perceived to be harsh on skin. To confirm their mildness on skin, detergents are evaluated for their potential to cause skin irritation through human in vivo patch testing. In vivo patch testing methodologies include Human Repeat Insult Patch Tests (HRIPT) and Cumulative Irritation Testing (CIT). These tests have been referred to as the “gold standard” for irritancy testing and represent the most common exposure of patients to detergent residues, which is washed fabrics in prolonged contact with human skin.[14] HRIPTs have been used to evaluate irritancy potential for over 50 years and have been called the most reliable test methods by which confirmatory human data can be made available.[15] These testing methodologies represent an investigation whose outcome is compared with that of historical controls, providing results that can be interpreted using the scientific method.[16,17] As such, dermatological associations, including the National Eczema Association, request patch testing data when evaluating consumer products for their seal of approval.

In vivo testing protocols have demonstrated that the leading commercially available free

detergents are of comparable mildness. A recently published 21-Day Cumulative Irritation Test showed that fabrics washed with Tide Pods Free & Gentle (TPFG) were as mild to skin as those washed with All Free Clear (AFC).[18] New in vitro methodologies have been proposed as a surrogate for in vivo testing for laundry detergent mildness.[19] While in vitro methods can be useful tools for rapid screening of large numbers of surfactants and product formulations, the ultimate test of mildness is contact with human skin in a controlled study with sufficient skin assessment end points to assure safe use on sensitive skin.[11,20-22]

While the mildness of commercially available free detergents is comparable, they vary considerably in their ability to remove laundry soils. A detergent's ability to clean is influenced by several factors, including shifts in consumer trends and advancements in technology. For instance, the rise of synthetic fabrics in clothing, such as polyester which are hydrophobic and more attracted to oils than hydrophilic, natural fibers like cotton, has created the need for new formulations. Furthermore, changes in washing machine technology, mainly the rise of high efficiency (HE) washing machines with lower, cooler wash water levels and temperatures, have had an influence as well. These changes require alterations in detergent formulations to provide optimal cleaning performance. Therefore, to adequately measure the cleaning efficacy of formulations, it is important to consider all of these factors.

RECOMMENDATIONS

Better Cleaning and Compliance with Dermatologist Recommendations

Consumer satisfaction with laundry detergents is predominately driven by cleaning performance.[23] Many people with sensitive skin believe they must compromise cleaning performance for mildness on skin. An internet survey of 3,175 people in the US who are responsible for their laundry and laundry product purchasing conducted from late 2014 through early 2015 showed that 39% of free detergent users are not satisfied with their detergent's cleaning performance. Additionally, 42% of free detergent users are not satisfied with their current product's ability to remove difficult stains.[24] Consumer purchase data shows that when consumers switch from the US-market leading free liquid detergent, All Free Clear, they will switch to a non-free detergent almost 60% of the time.[25]

An internet survey of 404 US households with sensitive skin conducted in December of 2017 shows that a strong majority of these consumers would prefer to use a free detergent that cleans better, would be willing to pay more for that detergent, and would consider it a better value. Notably, these consumers (98.8%) also said that they would be more likely to consistently use a detergent that cleans better (Table 1).

Due to these consumer trends and insights, a detergent that is mild on skin and provides better cleaning performance represents a product that may help to drive patient compliance with dermatologists' recommendations for free detergents.

Table 1. The Influence of Cleaning Performance on Consumer Behavior

99.3%	prefer to use a detergent that cleans better
85.9%	would be willing to pay more for a detergent that cleans better
96.8%	would consider a detergent that cleans better a better value
98.8%	would be more likely to consistently use a detergent that cleans better

COMPARISON

Comparing the Cleaning Performance of Commercial Free Detergents

ASTM International is a voluntary industry organization that publishes a standard guide for evaluating the stain removal performance of laundry detergents designed for in-home use.[26] These guidelines include the selection, preparation, application and examination of various types of stains on different types of test fabrics and testing in both traditional top load washing machines and in front load HE machines to simulate consumer experience as closely as possible. As the relative effectiveness of various laundry products will be influenced by the nature of the fabric, it is pointed out that testing may encompass more than one fiber composition. For reference, the three fabric types most common for the US laundry are polyester/cotton blends, 100% cotton, and 100% polyester. The guidelines recommend that at least 6 stains should be used in detergent cleaning evaluations and that stains may be selected to indicate various cleaning objectives, such as representing a specific cleaning mechanism or predicting an important consumer stain or stain class.

ASTM guidelines were followed to evaluate the stain removal performance of 3 free detergents available at retail in the US: Tide Pods Free & Gentle detergent pac (TPFG), All Free Clear liquid detergent (AFC), and Purex Free and Clear liquid detergent (PFC). Two of these free detergents are also available at retail in Canada: TPFG and PFC. While AFC and PFC are formulated as liquids, TPFG is formulated as a highly concentrated laundry detergent pac encased in a water-dissolvable membrane. ASTM guidelines recommend using at least 6 stains, whereas free detergents in this manuscript were evaluated across 18 stains to better predict real-world consumer experience.

Free detergents were purchased in late 2017 at retail locations in the US within 4 weeks of testing and dosed according to the manufacturer's label instructions for a medium wash load. Evaluations were performed in traditional top-loader (TL) washing machines and in front-loader HE washing machines, and on fabric swatches composed of 100% cotton or polycotton (a blend of 50% cotton/50% polyester; Empirical Manufacturing Company, Incorporated; Cincinnati, Ohio, USA) on the normal cycle. Stain strips for testing included 18 stains representing 10 technical stain categories, including Food Grease, Sebum, Grass, Particulates, and Colored Beverages/Food, among others.

Stain strips were washed one time in either a Whirlpool Duet high efficiency (HE) washing machine (Whirlpool Corporation,

Benton Harbor, Michigan, USA) on the normal cycle at 77°F wash/60°F rinse, or in a Kenmore Series 600 top-loader washing machine (Sears Holdings Corporation, Hoffman Estates, Illinois, USA) on the normal cycle at 86°F wash/60°F rinse with a manufacturer recommended dose for a medium laundry load of either TPFG, AFC or PFC using a mineral mixture representing the average water hardness in the USA (17.1ppm of minerals, 4:1 ratio of $CaCl_2$:$MgCl_2$). After the wash, fabrics were dried in a commercial clothes dryer on normal for 30 min.

The Stain Removal Index (SRI) was calculated using instrumental measurements of the reflectance of the stained fabrics and the unstained areas of the fabrics (for reference) before and after machine washing and drying. Treatment comparisons were made between TPFG and the other free detergents for each stain separately. The response analyzed was the average stain removal index across internal reps for each combination of machine, run, and treatment. A mixed model with fixed effects for treatment and run and a random effect for machine was used to model the data. The following set of hypotheses were tested at a type I error rate of 0.05 for each pair of treatments, adjusting for the multiple treatment comparisons using Tukey's "honestly significant difference" (HSD) procedure: Null Hypothesis = Treatment X and treatment Y are the same with respect to mean SRI; Alternative Hypothesis = Treatment X and treatment Y are different with respect to mean SRI.

TPFG consistently outperformed AFC and PFC across a wide variety of stain categories, across 2 fabrics and 2 types of washing machines. Stains in which the SRI was significantly higher (that is, significantly more of the stain was removed) with TPFG are indicated in green, stains in which the differences between treatments were not significantly different are indicated by a lack of color, and stains in which the SRI for TPFG was significantly lower (that is, significantly less of the stain was removed) are indicated in red.

Across both washing machines and both fabrics, TPFG outperformed AFC on 7 stains and underperformed on 2 stains, showing either better or parity performance on the remaining 9 stains (Table 2). Across both washing machines and both fabrics, TPFG outperformed PFC on 13 stains, showing either better or parity performance on 3 stains and worse or parity performance on 2 stains (Table 3). Notably, TPFG outperformed PFC on the removal of sebum, a major source of fabric malodor, across both washing machines and both fabrics and outperformed AFC on cotton fabrics in an HE washing machine. Interestingly, TPFG performed poorly on the mustard stain which is a pH-depended stain and as such is removed better with detergents like AFC and PFC which are formulated at a higher pH than TPFG, which has a more neutral pH of 7.8.

ANALYSIS

Scanning Electron Microscopy Analysis of Cleaning Performance

Grease and oil residues left behind by poorly performing laundry detergents can attract loose soils in the wash water and cause build-up on fabrics over time. To visualize soils on fibers, we washed the polycotton fabric swatches in a Kenmore 600 Series top-loader washing machine with 1 dose of either TPFG or 1 dose of AFC along with a

Table 2. Stain removal comparisons of Tide Pods Free & Gentle detergent pac (TPFG) vs. All Free Clear (AFC) liquid detergent.

Technical Stain Category	TPFG vs. AFC	Top Load Cotton	Top Load Polycotton	HE Cotton	HE PolyCotton
Food Grease	Burnt Butter				
	Cooked Beef				
	Dyed Bacon				
Sebum	Sebum				
Grass	Grass				
Non-Food Grease	Make-up Foundation				
Particulate	Black Todd Clay				
	US Clay				
Red Food	Spaghetti Sauce				
Colored Beverage/ Food	Wine				
	Tea				
	Coffee				
	Grape Juice				
	Blueberry				
pH-Sensitive Food	Mustard				
Protein-Sensitive Stains	Blood				
Starch-Sensitive Stains	Gravy				
	Chocolate Sauce				

TPFG Performed Better ■ Equal Performance □ AFC Performed Better ■

Table 3. Stain removal comparisons of Tide Pods Free & Gentle detergent pac (TPFG) vs Purex Free Clear (PFC) liquid detergent.

Technical Stain Category	TPFG vs. PFC	Top Load Cotton	Top Load Polycotton	HE Cotton	HE PolyCotton
Food Grease	Burnt Butter				
	Cooked Beef				
	Dyed Bacon				
Sebum	Sebum				
Grass	Grass				
Non-Food Grease	Make-up Foundation				
Particulate	Black Todd Clay				
	US Clay				
Red Food	Spaghetti Sauce				
Colored Beverage/ Food	Wine				
	Tea				
	Coffee				
	Grape Juice				
	Blueberry				
pH-Sensitive Food	Mustard				
Protein-Sensitive Stains	Blood				
Starch-Sensitive Stains	Gravy				
	Chocolate Sauce				

TPFG Performed Better ■ Equal Performance □ PFC Performed Better ■

technical swatch (Empirical Manufacturing Company, Cincinnati, Ohio, USA) embedded with 40g of soils (28 g of artificial body soil, 4 ml of vegetable oil, and 9 ml of a clay slurry) mimicking consumer relevant laundry soils equivalent to those found in a typical 6 pound load of laundry. The test swatches were washed on a normal cold cycle (60°F wash/60°F rinse) at 7 gpg water hardness then dried on the normal cycle for 30 min. This was repeated a total of 8 times.

Scanning electron microscopy (SEM) was utilized to visualize the soil residues adhering to the fibers on the treated fabrics (Hitachi S-4800, secondary electron detection, 2kV acceleration voltage; Hitachi, Ltd., Tokyo, Japan) at 2000x magnification. Fabric samples were sputter coated 150 seconds with 60:40 Au:Pd (Gatan Alto 2500) to minimize sample charging.

SEM evaluations of 50% polyester/50% cotton swatches washed 8 times with technical soil swatches showed noticeably less buildup of soils after treatment with TPFG vs. AFC. When examining the polyester fibers via SEM, there is more soil buildup on the swatch washed with AFC vs. TPFG (Figures 1 & 2). Similarly, when examining the cotton fibers via SEM, there is more soil buildup on the swatch washed with AFC vs. TPFG (Figures 3 & 4).

Figure 1. SEM Scan of Polyester Fibers on Polycotton Swatch Washed with AFC

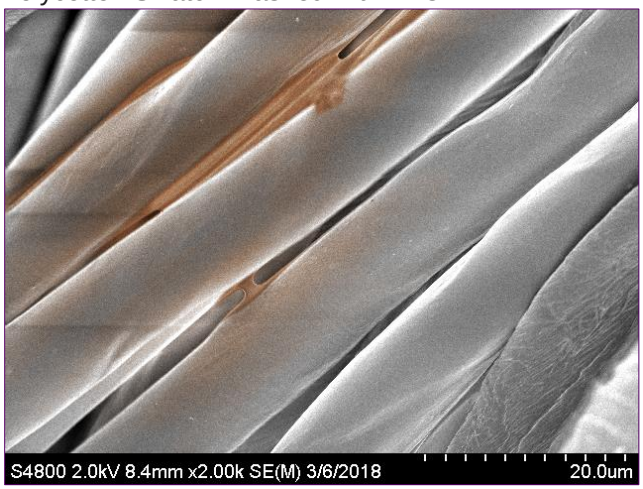

*Image has been colorized

Figure 2. SEM Scan of Polyester Fibers on Polycotton Swatch Washed with TPFG

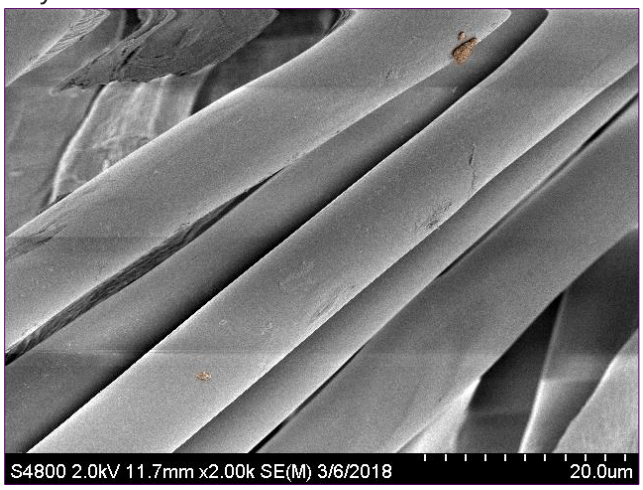

*Image has been colorized

CONCLUSION

In North America an overwhelming majority of dermatologist recommend the use of free detergents for their patients with sensitive skin, yet up until now very little research has been done to determine which factors can help to drive patient compliance with that recommendation. Retail purchase data demonstrate that all laundry detergents formulated for people with sensitive skin may not adequately serve the needs of this patient population. While mildness is comparable across detergents, cleaning performance is highly variable and can influence patient purchase decisions. Free detergent users report being unsatisfied with their free laundry detergents and up to 60% will switch to purchasing non-free

Figure 3. SEM Scan of Cotton Fibers on Polycotton Swatch Washed with AFC

*Image has been colorized

Figure 4. SEM Scan of Cotton Fibers on Polycotton Swatch Washed with TPFG

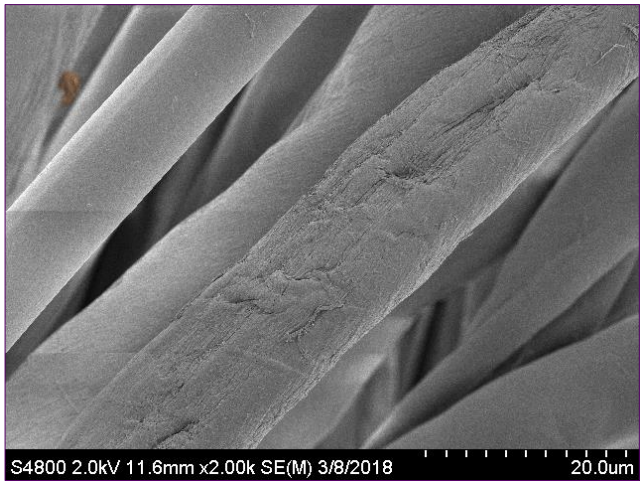

*Image has been colorized

detergents, going against dermatologist recommendations. A large-scale survey of US households with sensitive skin showed that 98.8% would be more likely to consistently use a detergent that cleans better. Studies reported in this paper demonstrated that Tide Pods Free & Gentle provided significantly better cleaning performance compared to two other leading free detergents across a variety of testing methodologies. The experimental design incorporated the broad range of stain categories free detergent users experience, the fiber composition of fabrics in laundry loads, as well as the types of washing machines present in their homes. By providing superior cleaning performance, Tide Pods Free & Gentle laundry pacs may help to improve compliance with dermatologist recommendations for use of a free detergent for their patients with sensitive skin. This is especially important for this patient population, as a change to a non-free laundry detergent may potentially increase the likelihood of skin irritation.

Conflict of Interest Disclosures: All authors are employees of The Procter & Gamble Company

Funding: This work was funded by The Procter & Gamble Company

Acknowledgments: The authors wish to thank Jenny Miller, Eric Moorhead, Fabrizio Meli, Sol Escobar, Will Shearouse, and Jack English for their assistance in the preparation of this manuscript.

Corresponding Author:
Mary Begovic Johnson, MS
5299 Spring Gove Avenue; Cincinnati, Ohio; 45217
Phone: 513-602-4252
Email: johnson.mb.3@pg.com

References:

1. Farage, M. A. (2009). How do perceptions of sensitive skin differ at different anatomical sites? An epidemiological study. Clinical and Experimental Dermatology, 34(8), e521–e530.
2. Misery, L., Sibaud, V., Merial-Kieny, C., & Taieb, C. (2011). Sensitive skin in the American population: prevalence, clinical data, and role of the dermatologist: Sensitive skin in USA. International Journal of Dermatology, 50(8), 961–967.
3. Farge, M. A., & Robinson, M. K. (2012). Sensitve Skin: Intrinsic and Extrinsic Contrbutors. In M. Lodén & H. I. Maibach (Eds.), Treatment of Dry Skin Syndrome (pp. 95–109). Berlin, Heidelberg: Springer Berlin Heidelberg.

4. Mohamoud, A. A., & Andersen, F. (2017). Allergic contact dermatitis caused by textile dyes mimicking atopic dermatitis: Allergic contact dermatitis caused by textile dyes. Contact Dermatitis, 76(2), 119–120.
5. Belsito, D. V., Fransway, A. F., Fowler, J. F., Sherertz, E. F., Maibach, H. I., Mark, J. G., Nethercott, J. R. (2002). Allergic contact dermatitis to detergents: A multicenter study to assess prevalence. Journal of the American Academy of Dermatology, 46(2), 200–206.
6. Krakowski, A., & Eichenfield, L.F. (2010). Atopic Dermatitis Basics: Three Common Myths Debunked. Practical Dermatology for Pediatrics. May/June, 39-42.
7. P&G data on file. US data is based on IQVIA ™ ProVoice January 2018 cumulative 12-month data. Canadian data is based on an internet survey of 150 dermatologists licensed to practice in Canada conducted in January 2018.
8. Ertel, K. (2000). Modern skin cleansers. Dermatologic Clinics, 18(4), 561–575.
9. Yamaguchi, F. Watanabe, S., Harada, F., Miyake, M., Yoshida, M. & Okano, T. (2014). In Vitro Analysis of the Effect of Alkyl-Chain Length of Anionic Surfactants on the Skin by Using a Reconstructed Human Epidermal Model. Journal of Olea Science, 63(10), 995-1004.
10. Mukhopadhyay, P. (2011). Cleansers and their role in various dermatological disorders. Indian Journal of Dermatology, 56(1), 2.
11. Crawford, C., & Zirwas, M.J. (2014). Laundry Detergents and Skin Irritancy- A Comprehensive Review, 12(1), 23-31.
12. Adrio, J., & Demain, A. (2014). Microbial Enzymes: Tools for Biotechnological Processes. Biomolecules, 4(1), 117–139.
13. Basketter, D. A., English, J. S. C., Wakelin, S. H., & White, I. R. (2008). Enzymes, detergents and skin: facts and fantasies. British Journal of Dermatology, 158(6), 1177–1181.
14. Bowman, J.P., Berger, R.S., Mills, O.H. (2003). The 21-day human cumulative irritation test can be reduced to 14 days without loss of sensitivity. J. Cosmet. Sci., 54, 443-449.
15. McNamee, P. M., Api, A. M., Basketter, D. A., Frank Gerberick, G., Gilpin, D. A., Hall, B. M., Robinson, M. K. (2008). A review of critical factors in the conduct and interpretation of the human repeat insult patch test. Regulatory Toxicology and Pharmacology, 52(1), 24–34.
16. Marzulli, F. N., & Maibach, H. I. (1980). Further studies of effects of vehicles and elicitation concentration in experimental contact sensitization testing in humans. Contact Dermatitis, 6(2), 131–133.
17. Basketter, D. A. (2009). The human repeated insult patch test in the 21st century: A commentary. *Cutaneous and Ocular Toxicology*, *28*(2), 49–53.
18. Brink, S., Wang, Y., Blum, B., Baccam, M., Varbanov, A., Boeh, V., Wang, Y., Christman, J., Cella, C.E., Johnson, M.B., Farage, M.A. (2019). Clinical skin mildness evaluations of direct and indirect exposure to two commercial laundry detergents with markedly different pH designed for sensitive skin using a hand-laundering model. Journal of Cosmetic Science, 70, 1-17.
19. Fowler, J.F., Zirwas, M.J., Napolitano, L., Coope-Epstein, J. and Russell, M. (2017). A new approach to formulating a milder laundry detergent for patients with sensitive skin. J Am Acad Dermatol. 76S, 17.
20. Demetrulias, J., Donnelly, T., Morhenn, V., Jessee, B., Hainsworth, S., Casterton, P., Bernhofer, L., Martin, K. and Decker, D. (1998). Skin2 -- an in vitro human skin model: the correlation between in vivo and in vitro testing of surfactants. Exp Dermatol. 7, 18-26.
21. Fujimura, T., Shimotoyodome, Y., Nishijima, T., Sugata, K., Taguchi, H. and Moriwaki, S. (2017). Changes in hydration of the stratum corneum are the most suitable indicator to evaluate the irritation of surfactants on the skin. Skin Res Technol. 23, 97-103.
22. Gabard, B., Chatelain, E., Bieli, E. and Haas, S. (2001). Surfactant irritation: in vitro corneosurfametry and in vivo bioengineering. Skin Res Technol. 7, 49-55.
23. Ferri, A., Osset, M., Abeliotis, K., Amberg, C., Candan, C., Owens, J., & Stamminger, R. (2016). Laundry performance: Effect of detergent and additives on consumer satisfaction. Tenside Surfactants Detergents, 53(4), 375–386.
24. P&G data on file
25. Neilsen 2017 laundry detergent retail sales data; www.Nielsen.com
26. ASTM D4265-14. Standard Guide for Evaluation Stain Removal Performance in Home Laundering. Accessed from: https://www.astm.org/Standards/D4265.htm