Adapting Skincare for Climate Change

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ABSTRACT

Climate change is beginning to impact all aspects of our lives including our skincare needs. This has prompted the development of "climate-adaptive" products and routines. Here we discuss climate change, the pressure to adapt skincare and the beauty industry, to meet the challenges ahead.

Weather, Climate and Climate Change

What is all the fuss about climate change and global warming when the weather outside is just as I expected? Consider for a moment, the weather where you are today. Whatever you are experiencing is mostly determined by hard to predict, interdependent variables such as air pressure, temperature, humidity and wind-speed, which all take place within the troposphere (the layer of Earth's atmosphere that runs from the earth's surface to a height of about 6–10 km) (1). People living in England near London, expect the summer to be warm and relatively dry, but in 2024, it was cold and wet, and this triggered discussions about sport being disrupted and how it always rains during Wimbledon tennis (2). Anecdotal or not, this observation is an excellent example of a short-term weather pattern. Climate on the other hand, describes averaged weather patterns for a given area over a long period of time, which typically is over 30 years or more.

Small changes in global temperatures can have large effects on local climates. Increasing global temperatures will make hotter days more likely and more intense, and experts do not consider the average global temperature increase of 1.1° C since 1880, to be small. More frightening still is that most of this warming (a rate of around 0.15-0.2 °C per decade) has happened since 1975 (3). As with all averages for global parameters, parts of the world, especially those with micro-climates such as on mountains, in valleys, forests and cities etc., will experience much higher or lower temperatures than the mean values. For example, Switzerland has warmed above the global average by 2.8 °C in the past 150 years (4). At the beginning of September 2024, it was announced that Switzerland had lived through the second hottest August since measurements began 160 years earlier (5).

Keywords

Climate change; Global warming; Climate-stripes; Human vulnerability; Geoskincare; Climate-adaptive skincare; Coffee crisis; Skin adaptation; Skin resilience; Sustainability; Ingredient scarcity; Climate combating actives.

In May 2018, climate scientist Prof. Ed Hawkins, shared on Twitter (now known as X), a bar chart using a colour scale from blue (cooler) to red (warmer), to show which years from 1850 onwards were warmer and which were cooler than the average temperature for 1971-2000. These bar chart climate-stripes have now become the standard way to clearly illustrate global warming (see figure 1). When average temperatures for different parts of the World are compared, Europe is seen as the fastest warming continent. The global temperatures for 2023 were confirmed to be the warmest on record by a significant margin, such that the colour needed to represent this extreme heat as a climate-stripe, exceeded the darkest shade of red in Hawkin's initial scale (6). On Sunday, July 21, 2024, the planet experienced its hottest day since records began, as the global average surface air temperature reached 17.09 °C (7).

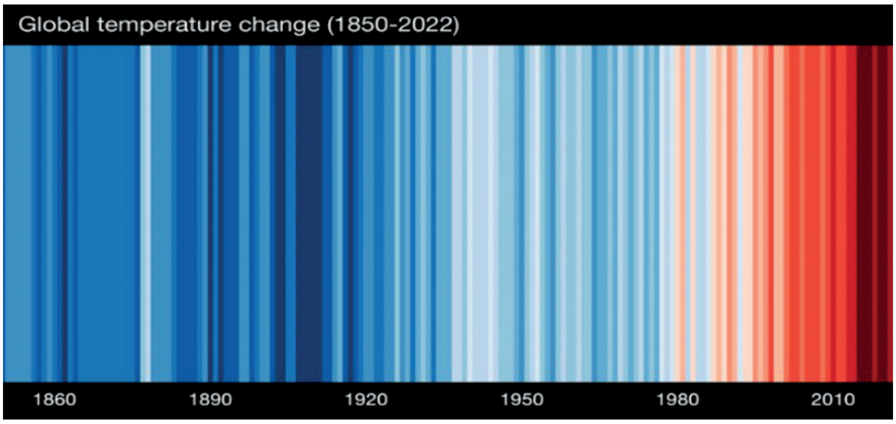

Figure 1. Hawkins' climate-stripes showing the change in average annual global temperatures since 1850 to 2022 against the average of the period 1971-2000 (UK Met Office) (6).

In 2024 the Northern Hemisphere experienced its second-warmest November on record at 1.92°C above average, with the Arctic region reaching 4.23°C above average. Similarly, the Southern Hemisphere ranked second-warmest at 0.76°C above average, though Antarctica was slightly below average at -0.08°C, with record-low sea ice (8).

While the Earth's climate is known to be dynamic and has changed many times since the atmosphere first formed, the current rate and magnitude of warming is unprecedented in recent geological history, and it is rapidly leading to intolerable conditions. As 2025 began, the European Copernicus Climate Service announced that globally, 2024 had become the hottest year on record. 1.6°C above the pre-industrial average and so 2024 is the first year to exceed the 1.5°C limit set in the Paris Agreement adopted by 196 Parties at the UN Climate Change Conference (COP21) in 2015.

Human vulnerability in a Warming World

Heat has already killed millions of Europeans. Epidemiological models applied to a mortality database representing over 543 million people, from 823 regions in 35 European countries, showed that despite the implementation of heat prevention plans (e.g., temperature threshold alert systems, emergency registry of vulnerable people, air-conditioned spaces in public buildings, water fountains and cooling centres in cities etc.,) since 2003, deaths due to heat in 2022 approached the record-breaking excess mortality of the 2003 heatwave, which saw over 70,000 excess deaths. Countries near the Mediterranean Sea were found to be particularly vulnerable to heat-related mortality. Italy suffered the highest number of deaths per million (285/m) totalling 18,010. This study stressed the need to re-evaluate and strengthen our current strategies for coping with excess heat and to focus first on the regions around the Mediterranean (9, 10).

In the northern hemisphere, the areas of distinct climate patterns (climate zones) are moving northwards, at an unparalleled rate. Back in 2020, the UK Environment Agency predicted British climate zones will be moving at 5km per year by 2050 (11). The Intergovernmental Panel on Climate Change (IPCC) calculated for the UK, that in order to stay in the same climate zone, living organisms, which of course includes people, need to move north at 5km a year on land and at least 10km a year in the sea. This migration rate is not practical for most organisms and would be 800 times faster than species recolonised the land after the last Ice Age (12, 13). As conditions rapidly worsen, human populations will try and relocate to the areas where the climate is less hostile. However, it is unrealistic to expect the 529 million people who live around the Mediterranean sea or the 1.43 billion people living in India, to simply mass migrate to safer regions. As ecosystems cannot adapt to keep pace with these rapid changes, there will be widespread crop failures and devastating harvests.

Coffee a Study in Resource Scarcity

The beauty industry must prepare for sourcing difficulties. Changes in temperature and precipitation patterns with more frequent episodes of extreme and unusu-

al weather, will disrupt supply chains and affect the quality, yields, and availability of commodity crops. Coffee is a compelling example of how changing weather patterns has made widely traded agricultural commodity difficult to source and therefore expensive (14). This globally loved drink is made from Arabica and or Robusta beans, both of which require specific growing conditions. Arabica beans, known for their smooth flavour, thrive in temperatures between 18°C and 21°C, with 24°C as their upper limit. Robusta, is more heat-tolerant, but prefers temperatures between 24°C and 30°C. Both varieties need rain during flowering and fruit development (15). A drought in 2021, followed by unusual frost, resulted in a dramatic fall in Brazil's coffee production in 2022. As Brazil produces most of the world's coffee, this led to a 6.3% increase in US retail coffee price. In 2023/24 high temperatures and drought in Vietnam, the second major coffee producer, contributed to global shortages and boosted price increases.
Unpredictable weather patterns, including erratic rainfall and temperature fluctuations, have taken a toll on the Vietnam coffee-growing regions such that now less areas are devoted to coffee cultivation. The IPCC paint a grim picture for the future of coffee in Vietnam. They predict that by 2050, the area suitable for growing coffee will be so small that Vietnam will no longer be a major exporter and by 2080 between 85% and 99.7% of land suitable for wild Arabica coffee may disappear from Vietnam completely (16).

The coffee crisis serves as a stark reminder of how climate change can impact agricultural products, which are crucial to both global trade and to our daily lives. It highlights the urgent need for more resilient crop varieties and for agriculture and industry to develop other coping strategies.

Climate change and resource scarcity are amongst the top five major megatrends influencing investors and driving society towards sustainable practices (17). The cosmetic and personal care industry is no exception as it relies heavily on ingredients derived from harvested biological sources including vegetable fats and oils and their derivatives. The availability of a long list of common key cosmetic ingredients, such as aloe vera extracts, cocoa butter, caffeine and coffee extracts, jojoba oil, coconut oil, shea butter, argan oil, grape seed oil, avocado oil, olive oil, green tea extract and countless more, will be impacted by climate change.
Clearly, future-proofing ingredient sourcing should be a high priority for the cosmetics industry. Biotechnology and green chemistry have important roles to play and hold the answers to creating alternative sustainable cosmetic materials and to developing resilient, climate-adaptive crops which are able to withstand climate-related stresses, such as droughts and extreme temperatures.

The Impact of Climate Change on Skin Health

Logically, the climate zones which are ideal for people, are those where outdoor living is comfortable, buildings do not require heating or air-conditioning, and seasonal fluctuations in the air pressure, temperature, sunlight, humidity levels etc., are conducive to good health. Human ingenuity and ability to take care of themselves allow populations to thrive in a range of ideal and non-ideal climate zones. The Köppen-Geiger classification system divides the world's climates into five main groups (A-E) based on temperature and precipitation patterns and these groups are then divided further into 30 subtypes (18). Generally, humans tend to flourish in C Group (Temperate Climates), D Group (Continental Climates) and in some A Group subtypes (Tropical Climates) that allow human habitation and have a balance of wet and dry seasons, suitable for agriculture. The skin, particularly its outermost layer (stratum corneum), serves as the body's protector against all that these environments can throw at us. It has evolved to successfully resist infection, repel pollution, maintain its barrier function, regulate temperature and transepidermal water loss, to synthesise vitamin D while producing melanin to help shield us from damaging ultraviolet (UV) light, in all these different habitable climates. However, as a direct consequence of climate change, skin is about to be exposure to greater levels of familiar aggressors and to other new challenges. Many more people are going to find themselves having to deal with weather extremes, including strong hot or icy winds and increased exposure to sunlight. Research indicates that warmer drier conditions are leading to increased drought and more wildfires (19). With wildfires comes smoke containing carbon monoxide, carbon dioxide, and high levels of particulate matter plus a heterogenous mixture of toxic substances e.g., aldehydes, sulfur dioxide, nitrogen oxides, polycyclic aromatic hydrocarbons (PAHs), and other volatile and non-volatile organic compounds, all known to exert harmful effects on skin (20). One of the reasons why experts do not consider the 1.1 ° increase in average global temperature as small, is because models predict there will be at least a 30% increase in lightning-ignited wildfires by 2060, compared to 2011 levels and so a 1 °C increase in average annual temperature could result in a 600 % increase in forest fires in parts of North America. Devastating fires, like those that hit the Los Angeles area in January this year, are likely to become more frequent. It was a change in climate, with very high winds arriving ahead of the normal rainy period that made it impossible for the Los Angeles firefighters to contain the massive fires.

Skin's Resilience and Adaptability

Skin's ability to respond to environmental stimuli is crucial for maintaining homeostasis and to shield the body from pollutants and adverse conditions. Vasodilation and sweating in hot environments helps cool the skin surface, while in the cold, vasoconstriction and goosebumps (piloerection) counteracts heat loss. Pollutants on skin, trigger a cascade of inflammatory related reactions and the skin's invisible shield, its microbiome, will rebalance so reducing damage by external aggressors. (21). However, disrupting the delicate balance of the skin microbiome can also cause various skin problems including rosacea. Sufferers of rosacea know well that their symptoms are worsened in extreme temperatures and by exposure to sunlight, pollution and to changes in humidity. These are all factors associated with climate change, which makes rosacea a useful model for studying the impact of climate change on skin health (22).

All skin's physiological responses are dynamic and happen so fast that to the skin's microbiome, they could be equivalent to *skin-weather.* However, just as weather and short term weather patterns are not climate, these fast reversible physiological responses are not adaptation. Staying with the weather analogy, sun tanning could be considered as being equivalent to a short-term weather pattern, like rain at Wimbledon, as tanning can take 1-2 days to fully develop and, once away from the sun, melanin production falls and the tan slowly fades. Skin pigmentation on the other hand, is an example of adaptation to climates with different levels of UV radiation. Our earliest ancestors developed dark skin, rich in protective pigments like eumelanin, in order to live in the intense equatorial sunlight. This pigmentation allowed sufficient UVB to penetrate skin for keratinocytes to synthesise vitamin D, while still protecting DNA, folate etc., from damage by the deeper reaching UVA radiation. As humans migrated across the globe, they were exposed to lower, more varying levels (including seasonal fluctuations) in UV radiation. The need for sufficient UVB to drive Vitamin D synthesis gave an evolutionary advantage to populations with less skin pigment in regions further away from the equator. The lightest-skinned populations evolved in areas with the least UVB radiation. For populations living in middle latitudes, the ability to tan became important because of seasonal UV variations. Interestingly, light skin and tanning ability evolved multiple times throughout human history. Skin pigmentation is a genetic adaptation regulated by epigenetic mechanisms. The precise roles of UV radiation in mechanisms such as DNA methylation, histone modification and the functions of the many noncoding RNAs involved, is still to be determined but undoubtedly, epigenetic factors do impact crucial genes and affect melanogenesis signaling pathways (23, 24, 25, 26).

Given sufficient evolutionary time, through the complex interplay between climate, genetics and skin physiology, skin has evolved a variety of climate-driven adaptations in addition to pigmentation, that affect its structure and function. For example, cold-adapted populations have slower shedding rates, thicker skin to help insulate and deeper blood vessels to favour heat conservation. Pore sizes are smaller in cold dry climates to reduce water loss and sebaceous glands are small but more active, producing plenty of *waterproofing* sebum. Environmental humidity levels significantly influence the quantities and composition of natural moisturizing factors and stratum corneum lipids in adapted skin (27). It may not be science fiction to foresee how, by increasing our knowledge of the molecular processes involved, molecular level interventions could be developed that fast track human adaptation to changing climate conditions.

Extremophiles: Sources of Climate Combating Actives

Inheritable adaptations have enabled life to exist in the most inhospitable places. These adapted life forms (extremophiles), include microbes, fungi, plants and animals, can be rich sources of exciting new actives to help us combat climate change. Some of these biochemicals (extremolytes) are already being used to dramatically transform biotechnology, helping us to gain knowledge and improve our health. For example, DNA polymerase I from *Thermus aquaticus* (Taq polymerase) is the most famous of the thermostable DNA polymerases. It withstands the high temperatures required for repeated cycles of DNA denaturation, annealing and extension, which is the core of the PCR reaction and so has made possible everything from rapid DNA sequencing (needed to reveal the skin microbiome) through to COVID-19 detection.

Studying extremophiles, large and small, gives us insights into how to survive in hostile climates as well as enabling the discovery of useful extremolytes. Larger animals have evolved a variety of different survival strategies to live in conditions such as those found in Death Valley (B Group in the Köppen-Geiger classification), which is one of the most extreme places on Earth. They face the primary challenges of water scarcity and intense heat (up to 56.67 °C). The Bighorn sheep endure dehydration by losing up to a third of their body weight but can rehydrate rapidly when water becomes available. In contrast, kangaroo rats have highly efficient kidneys that enable them to extract all necessary moisture from their diet and they produce concentrated urine and dry faeces to reduce water loss. When conditions are too extreme, desert tortoises retreat into underground burrows and enter a state of estivation (heat-related dormancy). Other animals, like coyotes and jackrabbits, live nocturnally to avoid the daytime heat. The Jackrabbits' very large ears help by efficiently radiating heat. Roadrunners have evolved an unusually high body temperature that allows them to be active during the day. These adaptations are as a result of countless generations living over thousands of years. Sadly, this is a luxury that the rapid pace of climate change will only allow rapid cell dividing microbes to exploit. However, these and other adaptations provide inspiration for new materials, structures, and systems designed to help humans combat extreme conditions (biomimicry) (28).

Climate Change Challenges

As the Earth continues to warm, the number of climate zones suitable for human life will decrease and make it harder for populations to find favourable areas to inhabit. Human ingenuity in construction, technology and farming practices etc., will help communities cope to a point but as already seen in Iran in 2023, eventually, some climate zones will become so hostile that human survival becomes impossible (29). Research into how the human species has already adapted to different climates is urgently needed. Knowing the biochemistry that underpins the unique skin characteristics found in populations living in different climate zones, could potentially lead to future-proofing skin products and greater skin resilience. Currently, moisturisers help skin retain water and prevent dry skin and chapped lips, when moisture levels fall below 30-50% relative humidity. In the future, the cosmetic industry will need to create climate-adaptive products that help populations live in more extreme conditions e.g., 'extreme-moisturisers' that provide deep skin protection enabling survival in extreme humidities, as low as Death Valley's 4% relative humidity.

The Evolving Role of Cosmetics: Beyond Beauty

Cosmetics will increasingly play a pivotal role in safeguarding and maintaining skin health, making their traditional focus on enhancing appearance and addressing perceived flaws, less important. Climate-adaptive skincare products that protect and bolster skin's resilience will become indispensable. Skin protection will gain in importance as wildfires worsen air quality. Consumers will need cleansers to remove pollutants and anti-pollution skincare products, that sooth and calm. Multifunctional actives to strengthen the immune system, combat damaging reactive oxygen species while encouraging DNA repair will be especially important. Hotter climates will favour lightweight breathable formulations that cool, hydrate and help skin retain moisture. Skin facing colder drier climates will benefit from water retaining richer products. Skin barrier strengthening and repair will become more important than ever, as environmental stressors damage skin integrity. Following the principles of biomimicry, cosmetics incorporating hyaluronic acid and ceramides, natural moisturizing factors and stratum corneum lipids etc., (at the levels seen in skin that has adapted to dry climates), would benefit people forced to move to drier regions. Rising global temperatures will drive demand for advanced super hydrating ingredients. Extremolytes from thermophiles adapted to live in dry conditions could prove to be very beneficial cosmetic actives. Resource scarcity will ensure less waste, as advances in biotechnology will enable more cosmetic actives such as saccharide isomerate to be made from industry byproducts.

The Geoskincare Trend

The geoskincare trend is already driving beauty giants including L'Oréal, Shiseido, Beiersdorf and Aveda, to develop cosmetics for the specific skin needs based on where consumers live. This level of personalisation considers the climate and unique local environmental factors, such as UV, pollution and humidity levels. It builds on the long-established seasonal skincare and hair care routines followed by people living in temperate climates. During temperate winter months, moving between indoor heating systems, air-conditioning and cold external conditions, particularly strong winds, compromises the skin barrier function, leading to increased transepidermal water loss, heightened sensitivity, irritation and itching. Cosmetics with high lipid content are essential for replenishing the stratum corneum's natural moisturizing factors and addressing drier, flakier and cracked skin. Autumn and Spring present distinct challenges, with fluctuating UV exposure and atmospheric humidity levels putting stress on skin that can trigger inflammatory responses leading to breakouts. In addition, pollen in spring can induce allergic reactions, redness, itching and inflammation. These seasonal variations typically have consumers moving to cosmetics that sooth and have barrier-repair properties. The summer period introduces risks of UV-induced damage, photoaging, and an increased risk of skin cancer. Excessive sweating in response to heat and warm air can lead to dehydration and clogged pores. Recommendations for summer skincare concentrate on photoprotection, barrier maintenance, soothing and cleansing. Geoskincare products go further than these seasonal cosmetics by including materials that help counter skin health issues brough on by unique climatic conditions and environmental challenges in specific geographic regions.

The Cosmetic Industry's Reaction to Climate Change

While some may still dispute the causes of climate change, conscious consumers, driven by concerns for the future, are demanding cosmetics that not only deliver results but also align with their values of environmental responsibility and ethical practices. As a result, Sustainability has moved from a niche trend to a necessity. Green washing is not acceptable, and the industry is expected to become more transparent. An increasing number of brands use cosmetic materials that are already fully traceable with their environmental and social impact disclosed from *cradle to gate*. Across the industry it can be seen that the amount of greenhouse gasses released during manufacturing and transport are being measured and reduced. The industry is moving towards following international best practice with more and more companies making a public pledge to reach Net Zero by 2050 or earlier. The actual carbon footprint of the cosmetic and personal care sector is complex, involving raw material producers, packaging manufacturers, distributors and logistics, retail companies and the consumer. There is no doubt however, that the beauty industry is responding to the crisis and unsustainable practices involving petroleum-derived materials, the inappropriate use of land, deforestation, etc., are being phased-out and replace by ecofriendly practices and the innovative use of biotechnology.

Conclusion

Climate encompasses long-term weather patterns in a region, and Hawkins' climate stripes vividly illustrate our current era of unprecedented global warming. As climate zones shift and environments become more challenging, developing strategies to help people adapt becomes crucial, given the impracticality of mass migrations to more hospitable areas. The effects of climate change are already evident in commodity scarcities that impact daily life. The cosmetic industry is moving towards minimising its environmental impact from *cradle to gate,* but it must also future proof its ingredient sourcing by securing supply chains and exploring new and alternative materials through sustainable technologies such as biotechnology and green chemistry. The beauty industry can contribute to climate adaptation by developing cosmetic products designed to help people withstand extreme conditions

The rapid pace of climate change will likely outpace our evolutionary adaptations, necessitating technological solutions. Insights from past skin adaptations and extremophile survival mechanisms may lead to groundbreaking skincare developments. Cosmetics are set to play a vital role in safeguarding and maintaining skin health under the new environmental pressures created by climate change.

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