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Stability-Preserved Lycopene and Nutritional Photoprotection: Human Evidence for Resistance to UV-Induced Skin Stress

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Abstract

Lycopene stability in an oil matrix was examined alongside human studies of nutritional photoprotection. The three optimized formulations contained 2.13-2.34% total lycopene, with 85.1-86.2% in the all-trans form. After 30 days at 45°C, total lycopene retention was 90.8-91.6%. Process comparisons were more variable: removing the oil-phase antioxidant system, extending extraction at high temperature, or using high-temperature enzyme inactivation reduced all-trans integrity and/or storage retention. Human tomato and lycopene studies use a repeated-intake design rather than an acute sunscreen model. Tomato paste providing about 16 mg/day lycopene for 10-12 weeks reduced UV-induced erythema, and randomized work also recorded changes in MMP-1, procollagen-related responses, mitochondrial DNA damage, and UV-responsive inflammatory markers. A 2024 systematic review/meta-analysis of 21 intervention trials reported favorable changes across erythema, minimal erythema dose, MMP-1, ICAM-1, skin thickness, and density. The formulation data define a chemically stable lycopene exposure for direct studies that pair plasma or skin carotenoid status with prespecified UV-response endpoints.

Keywords lycopene; photoprotection; ultraviolet radiation; erythema; skin aging; carotenoids; tomato; NVTIA®

Introduction

Oral carotenoid photoprotection develops over repeated intake. Human skin accumulates dietary carotenoids, while UV exposure generates photo-oxidative stress, inflammatory signaling, and extracellular-matrix responses. This differs from topical sunscreen use: the nutritional question is whether sustained carotenoid exposure changes the biological response to a standardized UV challenge.

That time course makes ingredient preservation relevant. Lycopene can isomerize or oxidize during heating, oxygen exposure, and storage. The lipid matrix evaluated here was produced under low-temperature, low-oxygen conditions with mixed tocopherols and L-ascorbyl palmitate in the oil phase. If the carotenoid content drifts during a 10-12 week intervention, the exposure being tested also drifts.

We therefore treated formulation stability and human skin response as two linked but separate questions. The first was whether the processed oil resin retained lycopene concentration and isomeric integrity. The second was which human endpoints have responded to repeated tomato/lycopene intake and are suitable for later testing of this specific matrix.

Materials and Methods

Formulation characterization

Lycopene-rich tomato peel was enzymatically disrupted, dehydrated by ethanol replacement, and contacted with a deoxygenated food-grade oil phase. Total lycopene and geometric isomers were measured by C30 HPLC. Accelerated storage was conducted at 45°C for 30 days. Comparator processes omitted mixed tocopherols/L-ascorbyl palmitate, used 60°C extraction for 90 min without headspace oxygen control, or used post-enzymatic treatment at 80°C for 10 min.

Human photoprotection evidence

Human evidence was identified through August 2026. Controlled interventions and systematic evidence syntheses were prioritized when they measured UV-induced erythema, minimal erythema dose, skin carotenoid status, MMP-related responses, inflammatory mediators, pigmentation, extracellular-matrix endpoints, or mitochondrial DNA damage. Tomato nutrient complexes were interpreted according to their complete phytonutrient composition rather than as purified lycopene trials.

Results

Lycopene composition and process-dependent preservation

Table 1. Analytical quality of the optimized lycopene lipid formulations

Formulation	Transfer rate (%)	Total lycopene (%)	All-trans (%)	Moisture (%)	Ethanol residue (%)	PV (mmol/kg)
F1	80.8	2.28	85.6	0.22	0.06	1.9
F2	78.2	2.13	86.2	0.25	0.07	2.0
F3	82.1	2.34	85.1	0.20	0.05	1.8

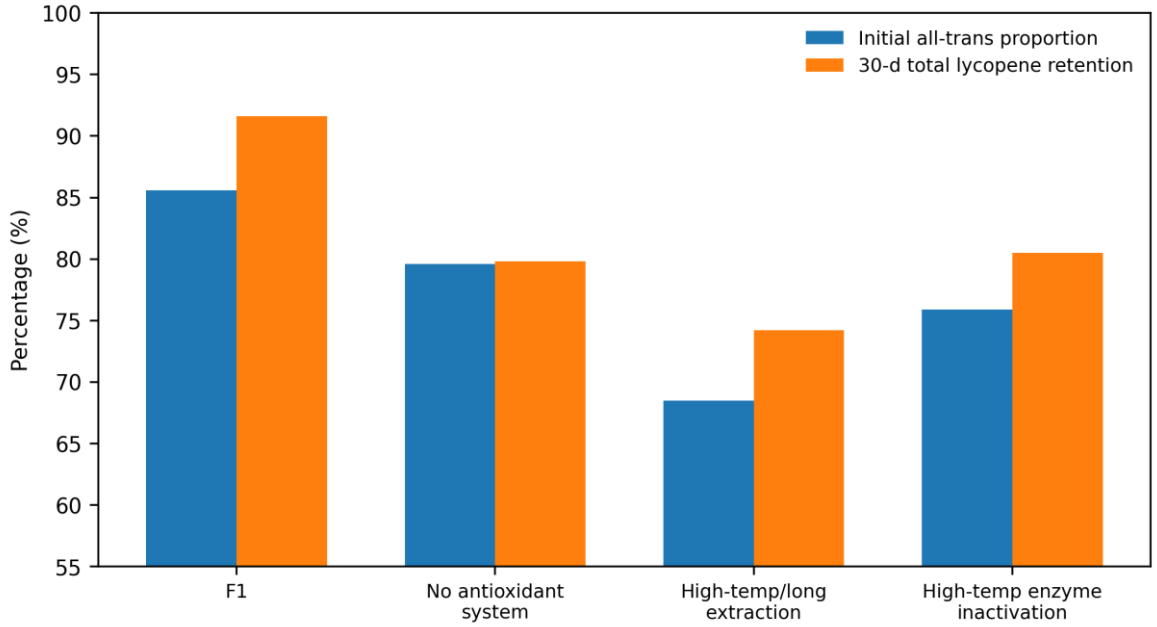


Figure 1. Initial all-trans lycopene proportion and 30-day total lycopene retention for the optimized formulation (F1) and selected process comparators. The figure uses direct analytical values and illustrates the sensitivity of lycopene integrity to antioxidant protection and thermal/oxygen control.

F1 contained 85.6% all-trans lycopene and retained 91.6% of total lycopene after accelerated storage. Without the oil-phase antioxidant system, the all-trans proportion was 79.6% and 30-day retention 79.8%. High-temperature, long-duration extraction produced 68.5% all-trans lycopene and 74.2% retention. High-temperature enzyme inactivation also reduced both measures. The analytical direction was consistent: more thermal or oxidative exposure was accompanied by greater loss of lycopene integrity.

Human evidence for oral photoprotection

Table 2. Representative human intervention evidence for tomato/lycopene and UV-response phenotypes

Study	Design / intervention	Skin endpoint	Main observation
Stahl et al. [1]	Controlled dietary intervention; tomato paste ~16 mg/d lycopene; 10 wk	UV-induced erythema	Erythema response at week 10 was ~40% lower than control
Aust et al. [2]	Clinical comparative supplementation; ~10 mg/d lycopene from different sources; 12 wk	UV-induced erythema	Erythema intensity decreased across lycopene sources; tomato phytonutrient matrices showed larger reductions
Rizwan et al. [3]	Randomized controlled trial; 20 healthy women; tomato paste 16 mg/d lycopene; 12 wk	Erythema, MMP-1, extracellular matrix and mtDNA	Tomato-paste intake increased resistance to UV-related erythema and modulated molecular photodamage markers

Study	Design / intervention	Skin endpoint	Main observation
Grether-Beck et al. [4]	Double-blind placebo-controlled crossover	UVA/B and UVA1-induced gene expression	Lycopene-rich tomato nutrient complex inhibited UV-induced HO1, ICAM1 and MMP1 expression
Groten et al. [5]	Double-blind randomized placebo-controlled multicenter study; 149 healthy volunteers; 12 wk	UVB erythema and cytokine response	Active carotenoid complex reduced chromametric erythema and UVB-induced IL6/TNFα upregulation
Zhang et al. [6]	Systematic review/meta-analysis; 21 intervention trials	Clinical and molecular photodamage outcomes	Pooled evidence favored lower erythema/MMP-1/ICAM-1 and higher MED, skin thickness and density

Stahl et al. used tomato paste supplying about 16 mg/day lycopene for 10 weeks and reported an erythema response approximately 40% lower than control at the end of the intervention [1]. Aust et al. compared several lycopene sources over 12 weeks; erythema intensity fell across the active sources, with larger changes in tomato phytonutrient matrices than with synthetic lycopene alone [2]. Rizwan et al. studied 20 healthy women for 12 weeks and extended the endpoint set beyond erythema to MMP-1, procollagen-related responses, and mitochondrial DNA photodamage [3].

Grether-Beck et al. measured UV-induced gene expression and found that a lycopene-rich tomato nutrient complex attenuated HO-1, ICAM-1, and MMP-1 responses [4]. In 149 healthy volunteers, Groten et al. reported lower chromametric UVB erythema and attenuation of IL-6 and TNF-α induction with an active carotenoid complex [5]. Zhang et al. pooled 21 intervention trials in 2024; the synthesis favored lower erythema, MMP-1, and ICAM-1 together with higher minimal erythema dose, skin thickness, and density [6].

Discussion

Photoprotection is a repeated-exposure nutritional phenotype

The clinical time course is slow enough that formulation drift matters. In the cited skin studies, the photoprotection signal developed over weeks rather than hours. The optimized oil resin retained more than 90% of total lycopene after the defined accelerated-storage challenge, so the ingredient can be carried into a longitudinal study with less uncertainty about loss of carotenoid content during use.

From singlet-oxygen quenching to UV-response signaling

The measured skin outcomes cover several biological levels. Erythema and minimal erythema dose describe the whole-skin UV response; MMP-1 and procollagen-related measurements address matrix remodeling; HO-1, ICAM-1, IL-6, and TNF-α add oxidative and inflammatory signaling. These endpoints need not change in parallel. A direct formulation study can select one primary UV-response measure and use the molecular markers as secondary outcomes rather than treating them as a single composite effect.

Whole-tomato phytonutrients and ingredient-specific interpretation

Tomato paste and tomato nutrient complexes contain more than lycopene. Phytoene, phytofluene, β-carotene, tocopherols, and other tomato constituents may contribute to the responses reported in several influential trials [1]-[5]. The published effect sizes therefore belong to those interventions. For the present oil resin, they are most useful for identifying exposure duration and skin endpoints that can be tested directly.

All-trans preservation and biological exposure

The high all-trans proportion is a process-quality marker, not a claim that the all-trans isomer must be the most bioavailable form. Gärtner et al. showed that lycopene from tomato paste was more bioavailable than from fresh tomatoes [7]. Unlu et al. later found greater bioavailability from a heat-induced cis-isomer-rich tomato sauce than from an all-trans-rich sauce [8]. Product isomer integrity and post-ingestion isomer handling are therefore related but distinct variables.

Older carotenoid trials reinforce the importance of sustained intake. Stahl et al. reported reduced UV-induced erythema after 12 weeks of carotenoids, with an additional vitamin E arm [9]. Heinrich et al. found a similar erythema reduction after 12 weeks with either β-carotene or a mixed-carotenoid supplement containing lycopene [10]. A meta-analysis of β-carotene trials found that protection depended on treatment duration rather than an immediate effect [11]. A later clinical review reached the same broad conclusion across ingestible carotenoid studies and also summarized molecular endpoints beyond erythema [12].

Exposure markers can be incorporated without relying only on reported intake. Scarmo et al. found significant correlations between dermal and plasma carotenoids, including lycopene, in healthy adults [13]. Darvin et al. reported an association between cutaneous lycopene concentration and skin roughness [14]. In unsupplemented adults, Alaluf et al. observed correlations between skin carotenoid levels and UV photosensitivity measured by minimal erythema dose [15]. These measurements are useful for separating carotenoid exposure from downstream UV-response outcomes.

Study Considerations and Future Directions

A direct trial can use the 10-12 week duration common in the tomato photoprotection literature. Plasma lycopene and a non-invasive skin-carotenoid measurement can document exposure. Chromametric erythema or minimal erythema dose can serve as a primary UV-response endpoint, with selected molecular or barrier measures added prospectively. Baseline carotenoid intake and skin phototype should be recorded before analysis.

Conclusion

The optimized lycopene oil formulations contained 2.13-2.34% total lycopene, 85.1-86.2% all-trans lycopene, and retained 90.8-91.6% of total lycopene after 30 days at 45°C. Process comparators exposed to less antioxidant protection or greater heat/oxygen stress showed larger losses. Human tomato/lycopene studies repeatedly use multi-week intake and UV-response endpoints ranging from erythema to molecular photodamage markers. The stable oil matrix is therefore suited to formulation-specific work in which carotenoid exposure and skin UV response are measured together.

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