

Stabilized White-Tomato Phytoene-Phytofluene Microcapsules: Formulation Performance and Clinical Context for Cutaneous Photoprotection

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ABSTRACT

Objective: Phytoene and phytofluene are colorless dietary carotenoids with ultraviolet-absorbing and redox-active properties. We examined a BCLC® white-tomato microcapsule enriched in these carotenoids and compared its measured formulation properties with published human oral-photoprotection studies. **Method:** The optimized microcapsules contained 6.31–7.58% total phytoene plus phytofluene, while colored carotenoids represented 2.77–4.12% of the colorless-carotenoid pool. After 30 days at 40°C/75% relative humidity, 82.7–88.6% of phytoene plus phytofluene remained. A 149-participant double-blind trial of a tomato nutrient complex supplying 5.8 mg/day phytoene plus phytofluene reported lower objective UVB-induced erythema and attenuated induction of IL-6 and TNF-α. Earlier tomato-product interventions also increased circulating phytoene and phytofluene and reduced UV-related erythema. **Results:** The optimized microcapsules contained 6.31–7.58% total phytoene plus phytofluene, while colored carotenoids represented 2.77–4.12% of the colorless-carotenoid pool. After 30 days at 40°C/75% relative humidity, 82.7–88.6% of phytoene plus phytofluene remained. A 149-participant double-blind trial of a tomato nutrient complex supplying 5.8 mg/day phytoene plus phytofluene reported lower objective UVB-induced erythema and attenuated induction of IL-6 and TNF-α. Earlier tomato-product interventions also increased circulating phytoene and phytofluene and reduced UV-related erythema. **Novelty:** The measured composition and stability of the BCLC® powder make it suitable for formulation-specific studies of UV response, skin carotenoid deposition and duration of effect.

INTRODUCTION

Ultraviolet exposure produces more than visible erythema. Repeated exposure alters cutaneous redox balance, activates inflammatory signaling and contributes to extracellular-matrix responses. Oral carotenoid studies approach this biology differently from topical sunscreens: the intervention is taken repeatedly, and the skin response is measured after a standardized ultraviolet challenge rather than by immediate optical shielding. Controlled tomato-carotenoid studies have used UV-induced erythema, circulating carotenoids and UV-responsive molecular markers to characterize that response [1]–[3].

Phytoene and phytofluene warrant separate consideration from the more strongly colored carotenoids. Their shorter conjugated systems leave them essentially colorless and shift their absorbance toward the ultraviolet region. Reviews describe their dietary occurrence, bioavailability and emerging relevance to skin nutrition [4]–[6]. Preliminary safety information has also been reported for phytoene- and phytofluene-rich products

intended for human use [7]. Their low visible color, together with measurable systemic exposure, makes these carotenoids practical targets for a pale oral formulation.

The wider photoprotection literature also gives a useful sense of exposure time. Repeated intake of tomato paste and beta-carotene or mixed-carotenoid supplements has been associated with reduced UV-induced erythema [8], [9]. A meta-analysis found that the magnitude of protection against sunburn was related in part to supplementation duration [10]. A later randomized trial extended the clinical endpoint to UVA-induced pigmentation [11], while earlier work with carotenoids plus vitamin E again used erythema after repeated intake [12]. These studies differ in composition, but they consistently evaluate sustained nutritional exposure rather than a single-dose effect.

Human studies using phytoene/phytofluene-predominant tomato preparations have broadened the endpoint set beyond erythema. Investigators have measured plasma carotenoids, perceived skin attributes, transepidermal water loss, barrier recovery and mechanical skin properties [13]–[15]. Those formulations are not identical to the BCLC® material, but the measurements are useful for deciding how a formulation-specific study can connect exposure with a cutaneous response.

The BCLC® white-tomato microcapsule was designed around a narrow carotenoid profile. It contains 5–9% total phytoene plus phytofluene by specification, while combined lycopene plus β -carotene is controlled to no more than 5% of the colorless-carotenoid pool. Concentrating the colorless fraction permits nutritionally relevant loading without the strong red-orange appearance associated with higher levels of visible carotenoids. Preserving that profile is a separate formulation problem because phytoene and phytofluene are unsaturated and sensitive to oxygen, light and heat. The process therefore uses low-temperature selective adsorption, antioxidant protectants and multilayer microencapsulation to limit colored-carotenoid carryover, reduce exposed oil and slow active loss. The present experiments measured those properties directly and then placed the resulting powder in the context of human UV-response research.

RESEARCH METHOD

White-tomato fruits were processed under light shielding and nitrogen protection with food-grade aqueous ethanol. Clarified extract was obtained by centrifugation and microfiltration and concentrated below 35°C. A food-grade nonionic styrene-divinylbenzene macroporous resin was used at low temperature to reduce colored carotenoids while retaining phytoene and phytofluene. The refined concentrate was combined with sodium starch octenyl succinate, a secondary wall material (resistant dextrin, gum arabic or inulin), hydroxypropyl methylcellulose, sucrose fatty acid ester and antioxidant protectants. High-shear dispersion and high-pressure homogenization preceded spray drying or freeze drying.

Carotenoids were measured by HPLC-DAD on a C30 column. Moisture, water activity, D90 particle size and free-oil content were measured with standard physicochemical methods. Heat-sealed aluminum-foil packs were stored for 30 days at

40°C and 75% relative humidity for accelerated testing. The literature comparison focused on peer-reviewed human oral-carotenoid studies that reported UV-induced erythema, pigmentation, inflammatory markers, circulating carotenoids or related photobiological endpoints [1]–[3], [8]–[12].

RESULTS AND DISCUSSION

Results

Table 1. Physicochemical and carotenoid characteristics of the evaluated formulations.

Formulation	Phytoene + phytofluene (%)	Colored carotenoids / colorless carotenoids (%)	Moisture (%)	Water activity	Free oil (%)	30-d retention (%)
BCLC formulation 1	7.58	2.77	4.1	0.29	1.3	88.6
BCLC formulation 2	6.79	3.53	4.3	0.31	1.5	85.2
BCLC formulation 3	6.31	4.12	4.8	0.34	1.7	82.7
Comparator 1: ordinary freeze- dried powder	0.62	29.03	5.8	0.42	0.2	59.4
Comparator 2: non- encapsulated ethanol-extract powder	9.84	7.32	4.6	0.27	6.8	62.8
Comparator 3: encapsulated without colored- carotenoid reduction	8.10	8.52	4.8	0.31	1.4	86.2

Total phytoene plus phytofluene was 7.58%, 6.79% and 6.31% in BCLC® formulations 1, 2 and 3. Colored carotenoids represented 2.77%, 3.53% and 4.12% of the colorless-carotenoid pool. Water activity was 0.29–0.34 and free oil was 1.3–1.7%. After accelerated storage, phytoene plus phytofluene retention was 88.6%, 85.2% and 82.7%. The ordinary freeze-dried powder retained 59.4%, and the non-encapsulated ethanol-extract powder retained 62.8%. Comparator 3, which was encapsulated without selective colored-carotenoid reduction, retained 86.2% but contained a larger colored-carotenoid fraction.

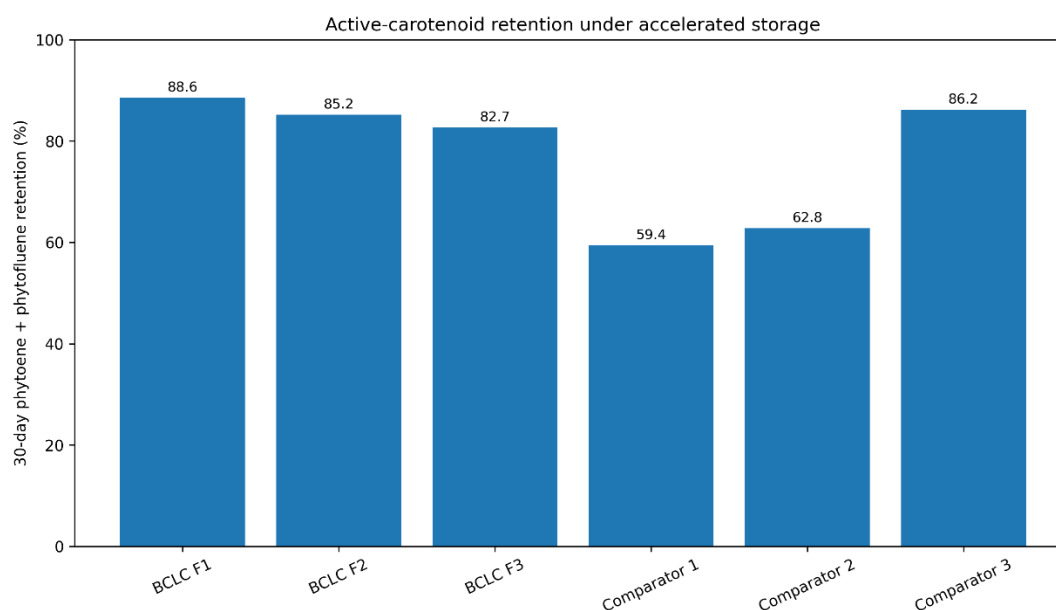


Figure 1. Active-carotenoid retention under accelerated storage.

Groten et al. randomized 149 healthy volunteers to a carotenoid-rich tomato nutrient complex or placebo for 12 weeks. The active intervention supplied 15 mg lycopene, 5.8 mg phytoene plus phytofluene, 0.8 mg β -carotene, tomato tocopherols and rosemary-derived carnosic acid per day. Minimal erythema dose did not differ significantly between groups. Objective chromametry, however, showed lower UVB-induced erythema in the active group, and skin biopsies showed attenuated UVB-induced IL-6 and TNF- α expression [1].

Aust et al. found that repeated intake of tomato-based products raised serum phytoene and phytofluene together with other tomato carotenoids and reduced UV-light-induced erythema [2]. Grether-Beck et al. reported lower induction of UV-responsive molecular markers, including heme oxygenase-1, ICAM-1 and MMP-1, after oral carotenoid supplementation [3]. Earlier trials with tomato paste, β -carotene/mixed-carotenoid supplements, or carotenoids with vitamin E also reported less UV-induced erythema after repeated intake [8], [9], [12]. A meta-analysis found the protective effect to be related to supplementation duration [10], and Baswan et al. later documented protection against UVA-induced pigmentation in a 12-week randomized trial [11].

Human Evidence Synthesis

Table 2. Key human studies relevant to the principal outcome.

Study	Design	Intervention	Endpoints	Main findings
Groten et al., 2019	Randomized, double-blind, placebo-controlled; 149 enrolled / 145 completed	12 weeks; 5.8 mg/day phytoene + phytofluene within tomato nutrient complex	UVB erythema, MED, IL-6, TNF- α	Lower objective erythema; attenuated IL-6 and TNF- α ; no significant MED difference

Study	Design	Intervention	Endpoints	Main findings
Aust et al., 2005	Human dietary intervention	12 weeks; tomato-based products	Serum carotenoids; UV erythema	Higher serum phytoene/phytofluene and reduced UV-induced erythema
Grether-Beck et al., 2017	Double-blind, placebo-controlled crossover	Carotenoid interventions	HO-1, ICAM-1, MMP-1 after UVA/UVA1	Reduced UV-inducible molecular stress markers

These human studies were used as external comparators for exposure duration and endpoint selection. The cited trials used other carotenoid formulations, so interpretation stayed at the level of oral carotenoid exposure, circulating or skin carotenoid measures, erythema or pigmentation responses, and inflammatory readouts. The BCLC® microcapsule can be evaluated against the same endpoint framework with its own defined composition and dose.

Discussion

For an oral carotenoid ingredient, storage behavior matters because photoprotection studies generally require repeated intake over several weeks. A powder that loses active carotenoid during storage weakens the intended exposure even when the starting assay is high. In the BCLC® formulations, 30-day accelerated retention remained 82.7–88.6%, with free oil at 1.3–1.7%. The non-encapsulated comparator retained 62.8%, whereas the encapsulated comparator without the adsorption step retained 86.2%. Stability and carotenoid selectivity were therefore separable formulation functions.

Phytoene and phytofluene are not simply less-colored versions of lycopene. Their shorter conjugated systems shift absorption toward the UV range, and their distribution in tissues differs from that of more highly conjugated carotenoids [4]–[6]. Human blood measurements show that both can rise after oral tomato-carotenoid intake [1], [2]. At nutritional exposure, their contribution to skin response is likely to involve antioxidant and inflammatory pathways in addition to direct spectral absorption. The reduced IL-6 and TNF- α response in the Groten trial is consistent with that broader mechanism [1].

The low colored-carotenoid ratio serves a separate formulation purpose. Keeping lycopene and β -carotene low relative to phytoene plus phytofluene gives a pale powder that can be used in capsules, tablets and light-colored oral products. Tocopherol-based antioxidant protection and a low free-oil fraction also limit exposure of the carotenoid-rich core to oxygen and moisture.

Trial designs in this field differ in carotenoid composition, dose, duration, baseline diet and UV challenge [1]–[3], [8]–[12]. Even with that heterogeneity, the human response is usually assessed after repeated exposure rather than after a single dose. Skin-appearance and barrier studies of phytoene/phytofluene-predominant tomato

carotenoids add a complementary line of evidence: the exposure is systemically measurable and can be followed with skin endpoints beyond erythema [13]–[15].

Current Scope and Future Directions

A formulation-specific BCLC® study can measure plasma and skin phytoene/phytofluene alongside standardized UVB chromametry, erythema recovery and inflammatory biomarkers. Sampling during a washout period would show how long the response persists after intake stops. This design would test the exposure–response relationship of the colorless-carotenoid-dominant microcapsule while keeping oral nutritional photoprotection distinct from topical sun protection.

CONCLUSION

Fundamental Finding : The BCLC® white-tomato microcapsules contained 6.31–7.58% phytoene plus phytofluene, limited colored carotenoids to 2.77–4.12% of that pool, and retained 82.7–88.6% of the active fraction after 30 days at 40°C/75% relative humidity. **Implication :** Human tomato-carotenoid trials have reported lower UVB erythema, reduced UV-responsive inflammatory or molecular markers, and increased resistance to UVA-induced pigmentation after repeated oral exposure. **Limitation :** The available findings do not establish the clinical photobiological effects of the BCLC® formulation itself. **Future Research :** The BCLC® formulation offers a defined low-color delivery system for testing those photobiological endpoints with formulation-specific dosing.

REFERENCES

- [1] K. Groten, A. Marini, S. Grether-Beck, T. Jaenicke, S. H. Ibbotson, H. Moseley, J. Ferguson, and J. Krutmann, “Tomato phytonutrients balance UV response: Results from a double-blind, randomized, placebo-controlled study,” *Skin Pharmacol. Physiol.*, vol. 32, no. 2, pp. 101–108, 2019, doi: 10.1159/000497104.
- [2] O. Aust, W. Stahl, H. Sies, H. Tronnier, and U. Heinrich, “Supplementation with tomato-based products increases lycopene, phytofluene, and phytoene levels in human serum and protects against UV-light-induced erythema,” *Int. J. Vitam. Nutr. Res.*, vol. 75, no. 1, pp. 54–60, 2005, doi: 10.1024/0300-9831.75.1.54.
- [3] S. Grether-Beck, A. Marini, T. Jaenicke, W. Stahl, and J. Krutmann, “Molecular evidence that oral supplementation with lycopene or lutein protects human skin against ultraviolet radiation: Results from a double-blinded, placebo-controlled, crossover study,” *Br. J. Dermatol.*, vol. 176, no. 5, pp. 1231–1240, 2017, doi: 10.1111/bjd.15080.
- [4] A. J. Meléndez-Martínez, C. M. Stinco, and P. Mapelli-Brahm, “Skin carotenoids in public health and nutricosmetics: The emerging roles and applications of the UV radiation-absorbing colourless carotenoids phytoene and phytofluene,” *Nutrients*, vol. 11, no. 5, Art. no. 1093, 2019, doi: 10.3390/nu11051093.
- [5] N. J. Engelmann, S. K. Clinton, and J. W. Erdman Jr., “Nutritional aspects of phytoene and phytofluene, carotenoid precursors to lycopene,” *Adv. Nutr.*, vol. 2, no. 1, pp. 51–61, 2011, doi: 10.3945/an.110.000075.

- [6] A. J. Meléndez-Martínez, P. Mapelli-Brahm, A. Benítez-González, and C. M. Stinco, “A comprehensive review on the colorless carotenoids phytoene and phytofluene,” *Arch. Biochem. Biophys.*, vol. 572, pp. 188–200, 2015, doi: 10.1016/j.abb.2015.01.003.
- [7] F. Havas, S. Krispin, A. J. Meléndez-Martínez, and L. von Oppen-Bezalel, “Preliminary data on the safety of phytoene- and phytofluene-rich products for human use including topical application,” *J. Toxicol.*, vol. 2018, Art. no. 5475784, 2018, doi: 10.1155/2018/5475784.
- [8] W. Stahl, U. Heinrich, S. Wiseman, O. Eichler, H. Sies, and H. Tronnier, “Dietary tomato paste protects against ultraviolet light-induced erythema in humans,” *J. Nutr.*, vol. 131, no. 5, pp. 1449–1451, 2001, doi: 10.1093/jn/131.5.1449.
- [9] U. Heinrich, C. Gärtner, M. Wiebusch, O. Eichler, H. Sies, H. Tronnier, and W. Stahl, “Supplementation with beta-carotene or a similar amount of mixed carotenoids protects humans from UV-induced erythema,” *J. Nutr.*, vol. 133, no. 1, pp. 98–101, 2003, doi: 10.1093/jn/133.1.98.
- [10] W. Köpcke and J. Krutmann, “Protection from sunburn with β -carotene—A meta-analysis,” *Photochem. Photobiol.*, vol. 84, no. 2, pp. 284–288, 2008, doi: 10.1111/j.1751-1097.2007.00253.x.
- [11] S. M. Baswan, A. Marini, A. E. Klosner, T. Jaenicke, J. Leverett, M. Murray, K. W. Gellenbeck, and J. Krutmann, “Orally administered mixed carotenoids protect human skin against ultraviolet A-induced skin pigmentation: A double-blind, placebo-controlled, randomized clinical trial,” *Photodermatol. Photoimmunol. Photomed.*, vol. 36, no. 3, pp. 219–225, 2020, doi: 10.1111/phpp.12541.
- [12] W. Stahl, U. Heinrich, H. Jungmann, H. Sies, and H. Tronnier, “Carotenoids and carotenoids plus vitamin E protect against ultraviolet light-induced erythema in humans,” *Am. J. Clin. Nutr.*, vol. 71, no. 3, pp. 795–798, 2000, doi: 10.1093/ajcn/71.3.795.
- [13] E. Tarshish, K. Hermoni, Y. Sharoni, and N. Muizzuddin, “Effect of Lumenato oral supplementation on plasma carotenoid levels and improvement of visual and experiential skin attributes,” *J. Cosmet. Dermatol.*, vol. 21, no. 9, pp. 4042–4052, 2022, doi: 10.1111/jocd.14724.
- [14] E. Tarshish, K. Hermoni, Y. Sharoni, P. W. Wertz, and N. Dayan, “Effects of golden tomato extract on skin appearance—outlook into gene expression in cultured dermal fibroblasts and on trans-epidermal water loss and skin barrier in human subjects,” *J. Cosmet. Dermatol.*, vol. 21, no. 7, pp. 3022–3030, 2022, doi: 10.1111/jocd.14527.
- [15] E. Tarshish, K. Hermoni, and N. Muizzuddin, “Effect of Lumenato a tomato derived oral supplement on improving skin barrier strength,” *Skin Res. Technol.*, vol. 29, no. 11, Art. no. e13504, 2023, doi: 10.1111/srt.13504.

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