Supplementary Materials

Curcuma Bioactives and Curcuminoid Analogues in Melanogenesis: A Scoping Review of Experimental and Clinical Evidence

Qian Li[1], Azeana Zahari[1], Muhamad Aqmal Othman[1], Nurul Aishah Khairuddin[2], Sook Yee Liew[3,*], Syazreen Nadia Sulaiman[3,*]

[1] Department of Chemistry, Faculty of Science, Universiti Malaya, Kuala Lumpur 50603, Malaysia; lq19970825@gmail.com (Q.L.); azeanazahari@um.edu.my (A.Z.); aqmal@um.edu.my (M.A.O.)

[2] Social Science Division, Centre for Foundation Studies in Science, Universiti Malaya, Kuala Lumpur 50603, Malaysia; nurulaishah@um.edu.my

[3] Chemistry Division, Centre for Foundation Studies in Science, Universiti Malaya, Kuala Lumpur 50603, Malaysia

*Correspondence: joeyliew5382@um.edu.my (S.Y.L.); syazreen@um.edu.my (S.N.S.);

Tel.: +60-379-675-988 (S.Y.L.); +60-379-675-989 (S.N.S.)

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Supplementary S1

Preferred Reporting Items for Systematic reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR) Checklist

SECTION	ITEM	PRISMA-ScR CHECKLIST ITEM	REPORTED ON PAGE #
TITLE			
Title	1	Identify the report as a scoping review.	1
ABSTRACT			
Structured summary	2	Provide a structured summary that includes (as applicable): background, objectives, eligibility criteria, sources of evidence, charting methods, results, and conclusions that relate to the review questions and objectives.	2
INTRODUCTION			
Rationale	3	Describe the rationale for the review in the context of what is already known. Explain why the review questions/objectives lend themselves to a scoping review approach.	3
Objectives	4	Provide an explicit statement of the questions and objectives being addressed with reference to their key elements (e.g., population or participants, concepts, and context) or other relevant key elements used to conceptualize the review questions and/or objectives.	3
METHODS			
Protocol and registration	5	Indicate whether a review protocol exists; state if and where it can be accessed (e.g., a Web address); and if available, provide registration information, including the registration number.	3-4
Eligibility criteria	6	Specify characteristics of the sources of evidence used as eligibility criteria (e.g., years considered, language, and publication status), and provide a rationale.	4
Information sources*	7	Describe all information sources in the search (e.g., databases with dates of coverage and contact with authors to identify additional sources), as well as the date the most recent search was executed.	4
Search	8	Present the full electronic search strategy for at least 1 database, including any limits used, such that it could be repeated.	4 and Table S1
Selection of sources of evidence†	9	State the process for selecting sources of evidence (i.e., screening and eligibility) included in the scoping review.	4-5
Data charting process‡	10	Describe the methods of charting data from the included sources of evidence (e.g., calibrated forms or forms that have been tested by the team before their use, and whether data charting was done independently or in duplicate) and any processes for obtaining and confirming data from investigators.	5
Data items	11	List and define all variables for which data were sought and any assumptions and simplifications made.	5
Critical appraisal of individual sources of evidence§	12	If done, provide a rationale for conducting a critical appraisal of included sources of evidence; describe the methods used and how this information was used in any data synthesis (if appropriate).	Not applicable
Synthesis of results	13	Describe the methods of handling and summarizing the data that were charted.	5

SECTION	ITEM	PRISMA-ScR CHECKLIST ITEM	REPORTED ON PAGE #
RESULTS			
Selection of sources of evidence	14	Give numbers of sources of evidence screened, assessed for eligibility, and included in the review, with reasons for exclusions at each stage, ideally using a flow diagram.	5-6
Characteristics of sources of evidence	15	For each source of evidence, present characteristics for which data were charted and provide the citations.	8-21 and Table S2
Critical appraisal within sources of evidence	16	If done, present data on critical appraisal of included sources of evidence (see item 12).	Not applicable
Results of individual sources of evidence	17	For each included source of evidence, present the relevant data that were charted that relate to the review questions and objectives.	8-21
Synthesis of results	18	Summarize and/or present the charting results as they relate to the review questions and objectives.	22
DISCUSSION			
Summary of evidence	19	Summarize the main results (including an overview of concepts, themes, and types of evidence available), link to the review questions and objectives, and consider the relevance to key groups.	22
Limitations	20	Discuss the limitations of the scoping review process.	25
Conclusions	21	Provide a general interpretation of the results with respect to the review questions and objectives, as well as potential implications and/or next steps.	26
FUNDING			
Funding	22	Describe sources of funding for the included sources of evidence, as well as sources of funding for the scoping review. Describe the role of the funders of the scoping review.	26

JBI = Joanna Briggs Institute; PRISMA-ScR = Preferred Reporting Items for Systematic reviews and Meta-Analyses extension for Scoping Reviews.

* Where *sources of evidence* (see second footnote) are compiled from, such as bibliographic databases, social media platforms, and Web sites.

† A more inclusive/heterogeneous term used to account for the different types of evidence or data sources (e.g., quantitative and/or qualitative research, expert opinion, and policy documents) that may be eligible in a scoping review as opposed to only studies. This is not to be confused with *information sources* (see first footnote).

‡ The frameworks by Arksey and O'Malley (6) and Levac and colleagues (7) and the JBI guidance (4, 5) refer to the process of data extraction in a scoping review as data charting.

§ The process of systematically examining research evidence to assess its validity, results, and relevance before using it to inform a decision. This term is used for items 12 and 19 instead of "risk of bias" (which is more applicable to systematic reviews of interventions) to include and acknowledge the various sources of evidence that may be used in a scoping review (e.g., quantitative and/or qualitative research, expert opinion, and policy document).

From: Tricco AC, Lillie E, Zarin W, O'Brien KK, Colquhoun H, Levac D, et al. PRISMA Extension for Scoping Reviews (PRISMAScR): Checklist and Explanation. Ann Intern Med. 2018;169:467–473. doi: 10.7326/M18-0850.

Supplementary S2

Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) 2020 checklist

Section and Topic	Item #	Checklist item	Location where item is reported
TITLE			
Title	1	Identify the report as a systematic review.	Page 1
ABSTRACT			
Abstract	2	See the PRISMA 2020 for Abstracts checklist.	Page 2
INTRODUCTION			
Rationale	3	Describe the rationale for the review in the context of existing knowledge.	Page 3
Objectives	4	Provide an explicit statement of the objective(s) or question(s) the review addresses.	Page 3
METHODS			
Eligibility criteria	5	Specify the inclusion and exclusion criteria for the review and how studies were grouped for the syntheses.	Page 4
Information sources	6	Specify all databases, registers, websites, organisations, reference lists and other sources searched or consulted to identify studies. Specify the date when each source was last searched or consulted.	Page 4
Search strategy	7	Present the full search strategies for all databases, registers and websites, including any filters and limits used.	Table S1
Selection process	8	Specify the methods used to decide whether a study met the inclusion criteria of the review, including how many reviewers screened each record and each report retrieved, whether they worked independently, and if applicable, details of automation tools used in the process.	Page 4
Data collection process	9	Specify the methods used to collect data from reports, including how many reviewers collected data from each report, whether they worked independently, any processes for obtaining or confirming data from study investigators, and if applicable, details of automation tools used in the process.	Page 4-5
Data items	10a	List and define all outcomes for which data were sought. Specify whether all results that were compatible with each outcome domain in each study were sought (e.g. for all measures, time points, analyses), and if not, the methods used to decide which results to collect.	Not applicable
	10b	List and define all other variables for which data were sought (e.g. participant and intervention characteristics, funding sources). Describe any assumptions made about any missing or unclear information.	Not applicable
Study risk of bias assessment	11	Specify the methods used to assess risk of bias in the included studies, including details of the tool(s) used, how many reviewers assessed each study and whether they worked independently, and if applicable, details of automation tools used in the process.	Not applicable
Effect measures	12	Specify for each outcome the effect measure(s) (e.g. risk ratio, mean difference) used in the synthesis or presentation of results.	Not applicable
Synthesis methods	13a	Describe the processes used to decide which studies were eligible for each synthesis (e.g. tabulating the study intervention characteristics and comparing against the planned groups for each synthesis (item #5)).	Not applicable
	13b	Describe any methods required to prepare the data for presentation or synthesis, such as handling of missing summary statistics, or data conversions.	Not applicable

Section and Topic	Item #	Checklist item	Location where item is reported
	13c	Describe any methods used to tabulate or visually display results of individual studies and syntheses.	Not applicable
	13d	Describe any methods used to synthesize results and provide a rationale for the choice(s). If meta-analysis was performed, describe the model(s), method(s) to identify the presence and extent of statistical heterogeneity, and software package(s) used.	Not applicable
	13e	Describe any methods used to explore possible causes of heterogeneity among study results (e.g. subgroup analysis, meta-regression).	Not applicable
	13f	Describe any sensitivity analyses conducted to assess robustness of the synthesized results.	Not applicable
Reporting bias assessment	14	Describe any methods used to assess risk of bias due to missing results in a synthesis (arising from reporting biases).	Not applicable
Certainty assessment	15	Describe any methods used to assess certainty (or confidence) in the body of evidence for an outcome.	Not applicable
RESULTS			
Study selection	16a	Describe the results of the search and selection process, from the number of records identified in the search to the number of studies included in the review, ideally using a flow diagram.	Page 5 (Fig. 1)
	16b	Cite studies that might appear to meet the inclusion criteria, but which were excluded, and explain why they were excluded.	Not applicable
Study characteristics	17	Cite each included study and present its characteristics.	Page 8-21 and Table S2
Risk of bias in studies	18	Present assessments of risk of bias for each included study.	Not applicable
Results of individual studies	19	For all outcomes, present, for each study: (a) summary statistics for each group (where appropriate) and (b) an effect estimate and its precision (e.g. confidence/credible interval), ideally using structured tables or plots.	Not applicable
Results of syntheses	20a	For each synthesis, briefly summarise the characteristics and risk of bias among contributing studies.	Not applicable
	20b	Present results of all statistical syntheses conducted. If meta-analysis was done, present for each the summary estimate and its precision (e.g. confidence/credible interval) and measures of statistical heterogeneity. If comparing groups, describe the direction of the effect.	Not applicable
	20c	Present results of all investigations of possible causes of heterogeneity among study results.	Not applicable
	20d	Present results of all sensitivity analyses conducted to assess the robustness of the synthesized results.	Not applicable
Reporting biases	21	Present assessments of risk of bias due to missing results (arising from reporting biases) for each synthesis assessed.	Not

Section and Topic	Item #	Checklist item	Location where item is reported
			applicable
Certainty of evidence	22	Present assessments of certainty (or confidence) in the body of evidence for each outcome assessed.	Not applicable
DISCUSSION			
Discussion	23a	Provide a general interpretation of the results in the context of other evidence.	Page 22
	23b	Discuss any limitations of the evidence included in the review.	Page 25
	23c	Discuss any limitations of the review processes used.	Page 25
	23d	Discuss implications of the results for practice, policy, and future research.	Page 25-26
OTHER INFORMATION			
Registration and protocol	24a	Provide registration information for the review, including register name and registration number, or state that the review was not registered.	Page 3-4
	24b	Indicate where the review protocol can be accessed, or state that a protocol was not prepared.	Page 3-4
	24c	Describe and explain any amendments to information provided at registration or in the protocol.	Not applicable
Support	25	Describe sources of financial or non-financial support for the review, and the role of the funders or sponsors in the review.	Page 26
Competing interests	26	Declare any competing interests of review authors.	Page 26
Availability of data, code and other materials	27	Report which of the following are publicly available and where they can be found: template data collection forms; data extracted from included studies; data used for all analyses; analytic code; any other materials used in the review.	Not applicable

From: Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ 2021;372:n71. doi: 10.1136/bmj.n71. This work is licensed under CC BY 4.0. To view a copy of this license, visit https://creativecommons.org/licenses/by/4.0/

Table S1. The key words used for identification in 3 databases

Databases	Key words used	Amount
Sci-Finder	((curcuminoids AND curcuma) AND (nanoemulsion OR formulation OR pigmentation OR *anti AND aging* OR melanin OR tyrosinase OR cosmetics OR skin OR toxicity))	590
WOS	TS=((curcuminoids AND curcuma) AND (nanoemulsion OR formulation OR pigmentation OR *anti AND aging* OR melanin OR tyrosinase OR cosmetics OR skin OR toxicity))	239
Scopus	TITLE-ABS-KEY ((curcuminoids AND curcuma) AND (nanoemulsion OR formulation OR pigmentation OR *anti AND aging* OR melanin OR tyrosinase OR cosmetics OR skin OR toxicity))	110

Table S2. Characteristics and key findings of studies included in the scoping review

Author(s)	Year	Title	Geographic Distribution	Plant sources	Key Findings
Rungruang et al.	2021	Antioxidant and anti-aging enzyme activities of bioactive compounds isolated from selected Zingiberaceae plants	Thailand	*Curcuma longa* L., *Curcuma aromatica*	Ethanolic extracts from *C. longa* showed the highest copper chelating activity and strongest tyrosinase inhibition, along with anti-collagenase, anti-elastase, and DPPH/ABTS antioxidant activities with non-cytotoxic profiles in skin fibroblasts.
Goenka et al.	2019	Calebin-A Suppresses Alpha-Melanocyte-Stimulating Hormone-Induced Melanogenesis in B16F10 Mouse Melanoma Cells	USA	Commercial supplier (Calebin-A derivative)	Calebin-A (CBA) significantly suppressed alpha-MSH-induced melanin production in B16F10 melanoma cells without altering cell viability or directly inhibiting cell-free mushroom tyrosinase.
Firmansyah et al.	2023	Curcuma longa extract inhibits the activity of mushroom tyrosinase and the growth of murine skin cancer B16F10 cells	Indonesia	*Curcuma longa* L.	Ethanolic extract of *C. longa* rhizomes (ECL) contained curcuminoids, and showed weak mushroom tyrosinase inhibition, and also showed cytotoxic activity against B16F10 melanoma cells.
Kim et al.	2008	Inhibition of Mushroom Tyrosinase and Melanogenesis B16 Mouse Melanoma Cells by Components Isolated from Curcuma longa	South Korea	*Curcuma longa* L.	Bioassay-guided isolation yielded 11 compounds; natural curcuminoids (bisdemethoxycurcumin, demethoxycurcumin, curcumin) showed potent mushroom tyrosinase inhibition and reduced melanin synthesis in B16 melanoma cells.
Panich et al.	2010	Modulation of antioxidant defense by Alpinia galanga and Curcuma aromatica extracts correlates with their inhibition of UVA-induced melanogenesis	Thailand	*Curcuma aromatica*	The rhizome extracts suppressed UVA-induced tyrosinase activity, tyrosinase mRNA levels, and melanin production in G361 melanoma cells, inhibited cellular ROS formation, and restored antioxidant enzyme activities.

Athipornchai et al.	2021	Potent Tyrosinase Inhibitory Activity of Curcuminoid Analogues and Inhibition Kinetics Studies	Thailand	Commercial supplier (curcuminoid synthetic analogues)	Evaluated 14 synthetic curcuminoid derivatives; some of analogues exhibited potent monophenolase tyrosinase inhibition superior to kojic acid.
Adari Bhaskar Rao,	2014	Synthesis and Biological Evaluation of Glucosyl Curcuminoids	India	Commercial supplier (curcumin & tetrahydrocurcumin glucosyl conjugates)	Synthesized glucosyl-curcumin and glucosyl-tetrahydrocurcumin showed lower lipophilicity, enhanced water solubility, improved tyrosinase inhibition, DPPH radical scavenging, and selective cytotoxicity.
Kusumawati et al.	2018	Anti-aging properties of Curcuma heyneana Valeton & Zipj: A scientific approach to its use in Javanese tradition	Indonesia	*Curcuma heyneana*	Crude ethanol extract of *C. heyneana* demonstrated DPPH antioxidant activity, tyrosinase inhibition, collagenase inhibition, and topical application repaired UV-induced skin structural damage in rats in vivo.
Lee et al.	2010	Curcumin suppresses alpha-MSH-stimulated melanogenesis in B16F10 cells	South Korea	*Curcuma longa* L. (curcumin)	Curcumin significantly suppressed alpha-MSH-stimulated melanin synthesis and tyrosinase activity in B16F10 melanoma cells without toxicity, downregulating MITF and tyrosinase via activation of ERK and Akt pathways.
Jang et al.	2009	Partially purified Curcuma longa inhibits alpha-melanocyte-stimulating hormone-stimulated melanogenesis through extracellular signal-regulated kinase or Akt activation-mediated signalling in B16F10 cells	South Korea	*Curcuma longa* L.	Partially purified C. longa extract (PPC) suppressed alpha-MSH-stimulated melanin production and cellular tyrosinase activity in B16F10 cells.

Tu et al.	2012	Curcumin Inhibits Melanogenesis in Human Melanocytes	China	Commercial supplier (curcumin)	Curcumin inhibited melanin content, tyrosinase activity, and protein expression of MITF, tyrosinase, TRP-1, and TRP-2 in normal human melanocytes in a dose-dependent manne.
Goenka et al.	2021	Novel Chemically Modified Curcumin (CMC) Derivatives Inhibit Tyrosinase Activity and Melanin Synthesis in B16F10 Mouse Melanoma Cells	USA	Commercial supplier (chemically modified derivatives CMC2.14, CMC2.5, CMC2.23, CMC2.24)	Derivative CMC2.24 showed the highest potency as a tyrosinase inhibitor (mixed/competitive mode), superior to parent curcumin and kojic acid; CMC2.24 and CMC2.23 inhibited intracellular tyrosinase, cellular melanogenesis, and reduced MITF protein levels.
Lv et al.	2021	Inhibitory Effects of Curcumin Derivative J147 on Pigmentation in vitro and in vivo	China	Commercial supplier (curcumin derivative J147)	Curcumin derivative J147 inhibited tyrosinase activity and melanogenesis in B16F10 melanoma cells, reduced body pigmentation in zebrafish embryos in vivo, and decreased UV-induced skin hyperpigmentation in guinea pigs in vivo by downregulating MITF.
Jeon et al.	2023	Antimelanogenic Effects of Curcumin and Its Dimethoxy Derivatives: Mechanistic Investigation Using B16F10 Melanoma Cells and Zebrafish (Danio rerio) Embryos	South Korea	Commercial supplier (curcumin and dimethoxy derivatives)	Curcumin and its dimethoxy derivatives inhibited cellular tyrosinase activity and melanin synthesis in B16F10 melanoma cells, and reduced melanin pigment in zebrafish (Danio rerio) embryos in vivo without developmental toxicity.
Firmansyah et al.	2025	*Curcuma longa* L. (Zingiberaceae) extract protects against epithelial damage and reduces the expression of the microphthalmia-associated transcription factor in UVB-exposed Wistar rats	Indonesia	*Curcuma longa* L.	Topical application of *C. longa* ethanolic extract significantly reduced erythema severity, epithelial abrasion, inflammation, and epidermal melanin, while downregulating MITF expression in UVB-exposed Wistar rats in vivo.

Thanawala et al.	2025	Efficacy and Safety of Water-Dispersible Turmeric Extract Containing 60% Natural Curcuminoids (WDTE60N) in Skin Blemish and Complexion: A Randomized, Double-Blind, Placebo-Controlled Study	India	*Curcuma longa* (WDTE60N turmeric extract with 60% natural curcuminoids)	Oral administration of WDTE60N for 60 days significantly reduced facial skin blemish darkness/intensity, improved skin hydration and gloss, and reduced transepidermal water loss (TEWL) compared to placebo in human clinical trials.
Jovanović et al.	2025	Green Extraction of Bioactives from *Curcuma longa* Using Natural Deep Eutectic Solvents: Unlocking Antioxidative, Antimicrobial, Antidiabetic, and Skin Depigmentation Potentials	Serbia	*Curcuma longa* L.	Natural Deep Eutectic Solvents (NADES) efficiently extracted total phenolics and curcuminoids from *C. longa*; specific formulations exhibited high tyrosinase inhibition, DPPH/ABTS antioxidant capacity, alpha-amylase inhibition, and antibacterial activity.
Sumiyoshi et al.	2009	Effects of a turmeric extract (Curcuma longa) on chronic ultraviolet B irradiation-induced skin damage in melanin-possessing hairless mice	Japan	*Curcuma longa* L.	The oral administration of the turmeric extract (300 or 1000 mg/kg, twice daily) significantly reduced the increase in the expression of melanin granules in the stratum basale (basal layer) between the epidermis and corium caused by the chronic UVB irradiation from the histological observations.
Park et al.	2011	Aromatic-turmerone inhibits α-MSH and IBMX-induced melanogenesis by inactivating CREB and MITF signaling pathways	South Korea	Commercial supplier (ar-turmerone and curcumin)	Aromatic ar-turmerone significantly inhibited α-MSH and IBMX-induced melanin synthesis and tyrosinase activity in B16F10 melanoma cells with higher potency than curcumin. It downregulated tyrosinase, TRP-1, and TRP-2 expression by suppressing CREB phosphorylation and MITF transcription

Hosoya et al.	2012	Curcumin-like diarylpentanoid analogues as melanogenesis inhibitors	Japan	Commercial supplier (synthetic curcumin analogues)	Evaluated 47 synthetic curcumin analogues in B16 melanoma cells. Type-B methoxy-substituted cyclohexanone analogues showed the strongest anti-melanogenic effect; specifically, (2E,6E)-2,6-bis(2,5-dimethoxybenzylidene) cyclohexanone promoted melanin pigment degradation, while acyclic Type-A analogues (compounds 2, 11, 12) directly inhibited tyrosinase enzyme activity comparable to kojic acid.
Trivedi et al.	2017	Protective effects of tetrahydrocurcumin (THC) on fibroblast and melanoma cell lines in vitro: it's implication for wound healing	India	Commercial supplier (Tetrahydrocurcumin)	Tetrahydrocurcumin (THC) produced a 78.5% inhibition of α-MSH-stimulated melanin synthesis at a low concentration of 0.1μg/mL in B16-F10 cells, outperforming kojic acid via attenuation of intracellular cAMP levels1316. It also provided 61.2% protection against UVB photo-damage.
Rocchitta et al.	2022	Inhibitory Effect of Curcumin-Inspired Derivatives on Tyrosinase Activity and Melanogenesis	Italy	Commercial supplier (synthetic curcumin analogues)	Curcumin derivatives 1, 6, and 7 demonstrated potent nanomolar tyrosinase inhibition IC_{50}=11-24 nM. Brominated derivative 7 exhibited melanogenesis inhibition up to 4 times greater than arbutin at 100 μM in human melanoma cells through high-affinity binding at the tyrosinase catalytic site
Farooqui et al.	2022	Permeation enhancer nanovesicles mediated topical delivery of curcumin for the treatment of hyperpigmentation	India	*Curcuma longa* L.	Formulated curcumin-loaded permeation enhancer lipid nanovesicles (PE-NVs) with DMSO. In a sunlight-induced hyperpigmented rabbit model, topical PE-NVs significantly enhanced skin layer accumulation, reduced hyperpigmentation lesions, and decreased epidermal hyperpigmentation histopathologically compared to standard curcumin solution

Sumiyoshi et al.	2009	Effects of a turmeric extract (Curcuma longa) on chronic ultraviolet B irradiation-induced skin damage in melanin-possessing hairless mice	japan	*Curcuma longa*	The oral administration of the turmeric extract (300 or 1000 mg/kg, twice daily) significantly reduced the increase in the expression of melanin granules in the stratum basale (basal layer) between the epidermis and corium caused by the chronic UVB irradiation from the histological observations.
Park et al.	2011	Aromatic-turmerone inhibits α-MSH and IBMX-induced melanogenesis by inactivating CREB and MITF signaling pathways	Korea	Commercial supplier	Aromatic (ar)-turmerone significantly inhibited α-MSH and IBMX-induced melanin synthesis and tyrosinase activity in B16F10 melanoma cells with higher potency than curcumin. It downregulated tyrosinase, TRP-1, and TRP-2 expression by suppressing CREB phosphorylation and MITF transcription
Hosoya et al.	2012	Curcumin-like diarylpentanoid analogues as melanogenesis inhibitors	japan	Commercial supplier	Evaluated 47 synthetic curcumin analogues in B16 melanoma cells. Type-B methoxy-substituted cyclohexanone analogues showed the strongest anti-melanogenic effect; specifically, (2E,6E)-2,6-bis(2,5-dimethoxybenzylidene)cyclohexanone promoted melanin pigment degradation, while acyclic Type-A analogues (compounds 2, 11, 12) directly inhibited tyrosinase enzyme activity comparable to kojic acid.
Trivedi et al.	2017	Protective effects of tetrahydrocurcumin (THC) on fibroblast and melanoma cell lines in vitro: it's implication for wound healing	India	Commercial supplier	Tetrahydrocurcumin (THC) produced a 78.5% inhibition of α-MSH-stimulated melanin synthesis at a low concentration of 0.1μg/mL in B16-F10 cells, outperforming kojic acid via attenuation of intracellular cAMP levels1316. It also provided 61.2% protection against UVB photo-damage.

Rocchitta et al.	2022	Inhibitory Effect of Curcumin-Inspired Derivatives on Tyrosinase Activity and Melanogenesis	Italy	Commercial supplier	Curcumin derivatives 1, 6, and 7 demonstrated potent nanomolar tyrosinase inhibition IC50= 11- 24 nM. Brominated derivative 7 exhibited melanogenesis inhibition up to 4 times greater than arbutin at 100 μM in human melanoma cells through high-affinity binding at the tyrosinase catalytic site
Farooqui et al.	2022	Permeation enhancer nanovesicles mediated topical delivery of curcumin for the treatment of hyperpigmentation	India	*Curcuma longa*	Formulated curcumin-loaded permeation enhancer lipid nanovesicles (PE-NVs) with DMSO . In a sunlight-induced hyperpigmented rabbit model, topical PE-NVs significantly enhanced skin layer accumulation, reduced hyperpigmentation lesions, and decreased epidermal hyperpigmentation histopathologically compared to standard curcumin solution