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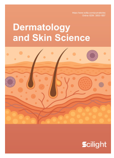

Review

Clothing Practices and Vitamin D Status in Healthy Adults: A Systematic Review and Meta-Analysis

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Abstract: Vitamin D plays a vital role in bone health, immune function, and physiological well-being, with deficiency (VDD) being a widespread global concern. One proposed risk factor for VDD is body-covering clothing, including modest dress worn for religious, cultural, or personal reasons, which may reduce skin exposure to ultraviolet B radiation, potentially impairing endogenous vitamin D synthesis. This systematic review and meta-analysis examines the association between clothing practices and vitamin D in healthy adults. A literature search was conducted to identify studies from databases between 1 January 1975 and 1 January 2026. The inclusion criteria were healthy adults (18–65 years old), all genders, English-language, randomized controlled trials, observational studies, and full-text papers. The exclusion criteria included pregnancy, smoking, symptomatic VDD, acute illness, chronic diseases, and intake of medications affecting vitamin D metabolism. Overall, 2203 studies were identified, and 35 articles underwent full-text assessment. Twenty-seven studies were excluded due to ineligible populations and insufficient outcome data. Eight observational studies were included, comprising 1043 participants. In random-effects analysis, serum 25(OH)D was 12.8 nmol/L lower in covered than uncovered individuals (95% CI −21.7 to −3.8; z = −2.79, p = 0.005), with substantial heterogeneity (I^2 = 93.7%; τ^2 = 113.2; Q = 52.5, df = 5, p < 0.001). Newcastle-Ottawa assessment revealed three studies rated good, four fair, and one poor. This review highlights the need for targeted public health interventions, including supplementation and education, to mitigate VDD risk in individuals who wear modest clothing, particularly those residing in northern latitudes.

Keywords: vitamin D deficiency; modest clothing; ultraviolet B radiation; systematic review; cultural practices

1. Introduction

Vitamin D plays a vital role in maintaining bone health, immune function, and overall physiological well-being [1,2]. While limited amounts of vitamin D can be obtained through diet, the majority is synthesized endogenously via skin exposure to ultraviolet B (UVB) radiation [2]. Vitamin D deficiency (VDD) is a prevalent global health concern, estimated to affect approximately one billion people worldwide [3]. Low vitamin D status has also been associated with several non-skeletal outcomes, including cardiometabolic disease and some cancers, although the strength of evidence varies by outcome [4,5]. Risk factors for VDD include limited sun exposure due to geographic location, seasonal variation in sunlight, skin pigmentation, age, body mass index (BMI), and personal or cultural practices that reduce skin exposure to sunlight, among other intrinsic and extrinsic determinants of vitamin D synthesis [6].

These clothing practices are often expressions of deeply held cultural and religious beliefs and personal identities, and it is critical to approach this topic with sensitivity and respect. The intention of this review is to promote awareness of VDD risk in individuals who may have less sun exposure, not to discourage, critique, or pathologize religious or cultural practices. Among the recognized risk factors for VDD, the use of modest or body-covering clothing, including garments such as shawls, robes, hijab, niqab, burka, chador, burqa, or long sleeves, has been proposed as one potential contributor, alongside geography, skin phototype, age, and sun exposure behavior, that may lower serum vitamin D levels through reduced cutaneous UVB exposure [6–8].

Canada is home to diverse religious and cultural communities, some of whose members wear modest or body-covering clothing as part of their religious observance, cultural identity, tradition, and personal practice. In the 2021 Census, approximately 1.78 million Canadians reported Muslim religious affiliation, representing 4.9% of the Canadian population [9]. A 2016 national survey reported that 53% of surveyed Muslim women wore a hijab, chador, or niqab in public, garments that vary in the extent of head, hair, face, or body coverage [10]. Similarly, approximately 335,000 Canadians reported Jewish religious affiliation in the 2021 Census [11]. Estimates suggest that approximately 30,000 Canadians belong to Haredi, or strictly Orthodox, Jewish communities [12]. Clothing practices within Orthodox and Haredi Jewish communities may include garments or head/hair coverings such as the kippah, tallit, kittel, tichel, sheitel, or other community-specific forms of dress; however, practices vary substantially by community, gender, setting, and individual observance [13]. For many individuals, these clothing practices may reflect deeply held values of modesty, spirituality, and cultural identity. At the same time, Canada's northern latitude (with a population-weighted mean of approximately 45.7° N and cities such as Edmonton situated at 53.5° N) substantially limits UVB availability during fall and winter, with no appreciable cutaneous vitamin D synthesis occurring from November through February [14,15]. In this context, reduced ambient UVB and the practice of modest dress may act as compounding factors, making vitamin D status in these communities a question of direct relevance to Canadian public health.

Although several studies have examined the relationship between clothing style and serum vitamin D levels, findings have been variable due to differences in study design, participant populations, clothing definitions, geographic setting, season of assessment, and confounding factors such as sun-exposure habits, dietary intake, and BMI [16]. This systematic review aims to synthesize the existing evidence regarding the association between modest or body-covering clothing practices and vitamin D status in healthy, asymptomatic adults. For the purpose of this review, "modest clothing" refers to garments that cover most of the body and may limit direct sunlight exposure to the skin.

The goal of this review is to provide evidence-based insights that may inform public health strategies, clinical counseling, and educational outreach. If an association is found, it may support culturally respectful health promotion efforts focused on vitamin D education, dietary sources or fortification, and supplementation when clinically appropriate. In doing so, this study aims to empower individuals and communities to make informed health decisions while maintaining their cultural and religious identities.

2. Methodology

2.1. Study Design and Search Strategy

A comprehensive review was conducted to evaluate serum vitamin D levels in healthy adults who wear head or body coverings, compared with those who do not. This study was completed according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 guidelines [17].

A thorough literature search was performed to identify all pertinent studies from 1 January 1975 to 1 January 2026, using various databases, such as PubMed, EMBASE, and Ovid MEDLINE. A meticulous combination of search terms was applied, including "adult*", "niqab", "hijab", "burka", "burqa", "chador", "dupatta", "veil*", "scarf", "shawl", "garment", "conceal*", "conservative", "facial cover*", "face cover*", "head cover*", "body cover*", "religio*", "Anabaptis*", "Amish", "Mennonite", "Hutterite", "Quaker", "Muslim", "Orthodox", "Christian", "nun", "monk", "priest", "minister", "vitamin D", "vit D", "hypovitaminosis D" and "25-hydroxyvitamin D".

2.2. Eligibility Criteria

The following inclusion criteria were implemented: human subjects, adults aged 18–65 years, any sex or gender, English-language, full-text papers, and articles available through open or institutional access. Randomized controlled trials (RCTs) and observational studies were included. We excluded animal studies, systematic reviews, meta-analyses, guidelines, grey literature, case reports, and articles that required purchase.

Participants: Healthy, asymptomatic adults ≥ 18 years old and ≤65 years old. Studies were excluded if participants were pregnant, smokers, acutely ill, had chronic diseases, had symptomatic vitamin D deficiency or used medications or supplements known to affect vitamin D metabolism or vitamin D status, such as bisphosphonates, corticosteroids, and vitamin D supplements.

Exposure: Use of head or body coverings labelled as "covered".

Comparator: Absence of head or body coverings labelled as "uncovered".

Outcome measures: The primary outcome was serum vitamin D concentrations. Included studies reported serum vitamin D concentrations as numerical values, rather than independently selected categories of vitamin D deficiency, insufficiency, or sufficiency.

2.3. Study Selection Process

Screening and data extraction were performed by one investigator (W.B.). All extracted data were subsequently re-verified against the source publications by a second investigator (E.Y.C.), and discrepancies were corrected. Duplicate and ineligible records were removed. Titles and abstracts were screened based on the inclusion and exclusion criteria. The remaining articles underwent a full-text assessment for inclusion in the final analysis. Reasons for exclusion at the full-text stage were recorded and summarized in the PRISMA flow diagram.

2.4. Data Extraction

A standardized data collection form was utilized to record the following information: study characteristics (author, year of publication, study design, country, sample size, and data collection period or season), participant characteristics (demographics, age, sex or gender, BMI, sun exposure, dietary intake and supplementation), exposure details (type and extent of traditional or body-covering clothing), comparator details (type of clothing or absence of head or body coverings), outcomes (serum 25-hydroxyvitamin D concentration and any secondary biochemical outcomes), and key findings. Where studies reported serum 25(OH)D in ng/mL, values were converted to nmol/L by multiplying by 2.496.

2.5. Risk of Bias Assessment

The methodological quality of included studies was assessed using the Newcastle-Ottawa Scale (NOS) adapted for cross-sectional studies [18]. The adapted scale awards a maximum of ten stars across three domains: Selection (five stars: representativeness of the sample, sample size, non-respondents, and ascertainment of the exposure, the latter worth two stars), Comparability (two stars: control for the most important and any additional confounders), and Outcome (three stars: assessment of outcome, worth two stars, and appropriateness of the statistical test). Two investigators independently applied the scale, and disagreements were resolved by consensus. Studies scoring 7–10 were considered good quality, 5–6 satisfactory, and 0–4 unsatisfactory.

2.6. Quantitative Synthesis

Meta-analysis was performed in JASP [19]. The effect measure was the mean difference in serum 25(OH)D (covered minus uncovered) in nmol/L. Values reported in ng/mL were converted to nmol/L (×2.496). For any studies reporting medians with interquartile ranges, means and standard deviations were estimated using the method of Wan et al. [20]. Studies were pooled using a random-effects model with restricted maximum likelihood estimation of between-study variance. Heterogeneity was quantified using τ^2, Cochran's Q, and I^2. Leave-one-out and sensitivity analyses were performed.

3. Results

During the initial database search, a total of 2203 records were identified. After removal of 131 duplicate records and 1448 ineligible records, 624 records underwent title and abstract screening. Of these, 541 records were excluded, leaving 83 reports for further assessment. Thirty-five full-text articles were retrieved and assessed for eligibility. Twenty-seven studies were excluded due to various reasons, such as ineligible participant populations, missing participant details, irrelevant exposure or comparator definitions, or insufficient outcome data. In the final analysis, eight cross-sectional observational studies were included, comprising 1043 patients. No RCTs were identified by the search. A detailed flowchart of the study selection process is shown in Figure 1.

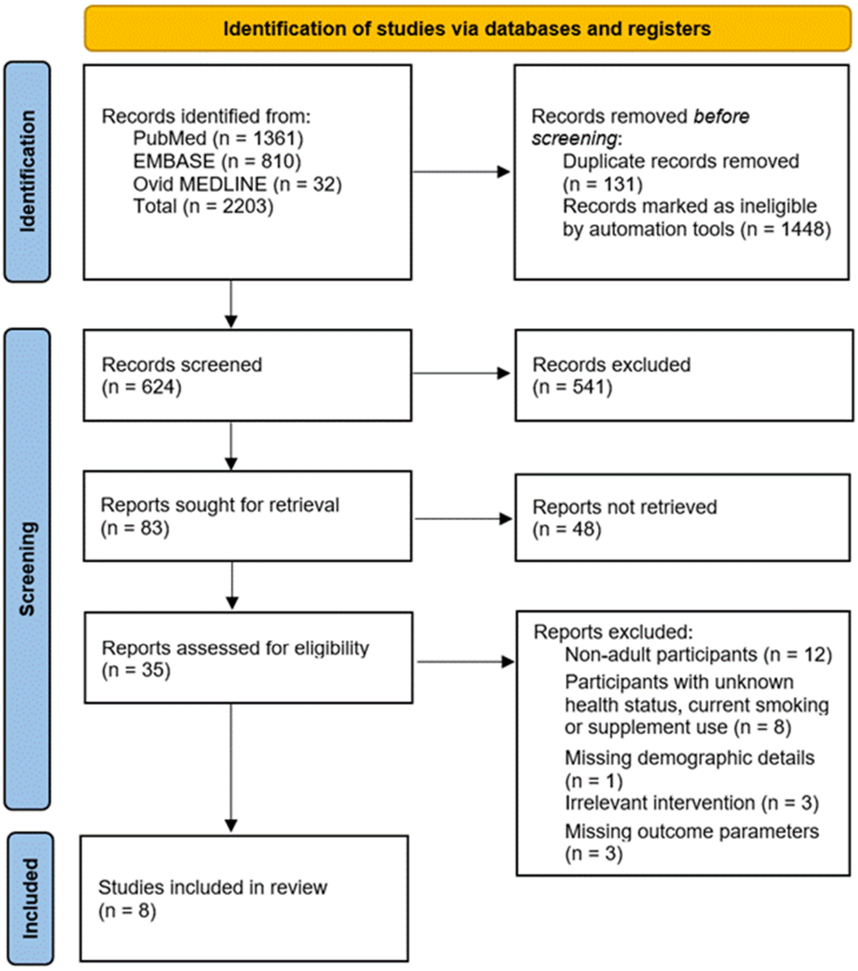

Figure 1. PRISMA 2020 Flow Chart, illustrating the study selection process. PRISMA: Preferred Reporting Items for Systematic Reviews and Meta-Analysis.

3.1. Study Characteristics

In the included studies, clothing practices were identified using the original authors' terminology, which typically reference religious or cultural community as a label for the intervention garment. In this review, these terms are used descriptively to reflect how each study categorized clothing practices, with the understanding that clothing type and extent of skin coverage, rather than religious or cultural identity, are the variables of interest. All eight studies utilized a cross-sectional design with a concurrent control group. Sample sizes ranged from 40 to 261 participants. They were conducted between 1998 and 2025 in sunny regions, such as Turkey, Lebanon, Greece, Bangladesh, Tunisia, Israel, and the United Arab Emirates. Seven studies collected blood samples during the same season, while one study retrieved samples during summer and winter. Every study applied a similar definition for the participants in the covered group: coverage of the whole body, except for the face, hands, and/or feet. Uncovered comparators included "Western style clothing" and the absence of traditional clothing. The primary outcome was serum 25-hydroxyvitamin D concentration, with various secondary outcomes of serum calcium, parathyroid hormone, alkaline phosphatase, phosphorus, albumin, osteocalcin, urinary-free deoxypyridinoline and creatinine, as outlined in Table 1. All studies had the same level of evidence (III) according to the 2011 Oxford Centre for Evidence-Based Medicine [21].

Table 1. Summary of included studies.

Author	Year	City, Country	Sample Size	Data Collection Period	Intervention (n)	Comparator (n)	Outcomes
Karras et al. [22]	2025	Thessaloniki, Greece	85	September 2023–March 2024	"Christian Orthodox traditional religious attire": entire body covered with face and hands exposed (40)	"Non-orthodox general population" (45)	1º: Serum 25(OH)D 2º: Serum PTH
Buyukuslu et al. [23]	2014	Istanbul, Turkey	100	April–May of the same year	"Muslim style clothing": entire body covered with face and hands exposed (40)	Uncovered (60)	1º: Serum 25(OH)D 2º: Serum Ca, PTH, ALP
Sayed-Hassan et al. [24]	2014	Damascus, Syria	188	May–October and November–April, from 2011 to 2013	"Hijab": head, arms, and legs covered with face and hands exposed (113)	"Non-veiled" (75)	1º: Serum 25(OH)D 2º: Serum Ca, iPTH
Tsur et al. [25]	2011	Jerusalem, Israel	51	March–April of the same year	"Traditional ultra-Orthodox clothing": >90% of body area covered (26)	"Western style clothing" (25)	1º: Serum 25(OH)D 2º: Serum Ca, PTH, phosphorus, albumin
Islam et al. [26]	2006	Dhaka, Bangladesh	66	June–July 2001	"Veiled": head, arms, and legs covered with face exposed or lightly covered (30)	"Non-veiled" (36)	1º: Serum 25(OH)D 2º: Serum Ca, ALP, phosphate
Meddeb et al. [27]	2005	Ariana, Tunisia	261	January-March 2002	"Veiled": head covered with face, hands and feet exposed (78)	"Non-veiled" (183)	1º: Serum 25(OH)D 2º: Serum Ca, PTH, ALP, phosphorus, albumin, Cr
Gannagé-Yared et al. [28]	2000	Bekaa Valley and Beirut, Lebanon	217	January-April 1999	"Veiled": head, arms, and legs covered with face and hands exposed (102)	"Non-veiled" (115)	1º: Serum 25(OH)D 2º: Serum Ca, PTH, ALP, phosphorus, albumin, osteocalcin, DPD
Dawodu et al. [29]	1998	Al Ain, UAE	75	June-September 1994	"Veiled" Group A: entire body covered with hands and feet exposed (33) "Veiled" Group B: entire body covered with face, hands and feet exposed (25)	"European style clothing" (17)	1º: Serum 25(OH)D 2º: Serum Ca, iPTH, ALP, phosphorus

25(OH)D: 25-hydroxyvitamin D; Ca: calcium; PTH: parathyroid hormone; iPTH: intact PTH; ALP: alkaline phosphatase; Cr: creatinine; DPD: urinary-free deoxypyridinoline; UAE: United Arab Emirates; words in quotations are the original study terms.

3.2. Participant Characteristics

This systematic review included a total of 1043 participants, with 992 of these individuals being female (95%). Seven studies investigated women only, whereas the eighth study evaluated men. The mean age of participants ranged from 19.8 to 52.4 years old. BMI was reported in five studies, and sun exposure as a unit of time was described in three studies. Participant characteristics were relatively homogenous within each study; however, there were significant differences in mean age in two studies and BMI in one study, as shown in Table 2.

Table 2. Participant demographic and biological parameters.

Study	Intervention	Sample Size	Mean Age (Years)	Female (%)	BMI (kg/m^2)	Sun Exposure (as Reported)	Mean 25(OH)D (nmol/L)	*p* Value for 25(OH)D
Karras et al. [22]	Covered	40	52.4 ± 17.5	100	27.3 ± 4.9	4.23 ± 1.2 h/week *	56.16 ± 21.72	0.062
	Uncovered	45	49.6 ± 14.3	100	25.9 ± 3.8	11.2 ± 3.8 h/week *	65.89 ± 22.71	
Buyukuslu et al. [23]	Covered	40	20.6 ± 1.7	100	24.0 ± 4.0 *	NA	52.8 ± 16.8	<0.001 **
	Uncovered	60	21.2 ± 2.3	100	22.3 ± 3.1 *		74.3 ± 7.8	
Sayed-Hassan et al. [24]	Covered	113	35.9 ± 10.6	100	26.3 ± 5.2	NA	13.2 (10.0–21.6)	0.042 *
	Uncovered	75		100			17.1 (10.0–33.1)	
Tsur et al. [25]	Covered	26	20.1 ± 0.6	0	NA	18.2 ± 18.8 ** sun exposure index	22.3 ± 9.0	<0.05 *
	Uncovered	25	19.8 ± 2.0	0		68.0 ± 30.6 ** sun exposure index	54.2 ± 26.0	
Islam et al. [26]	Covered	30	47.7 ± 9.4 **	100	22.2 ± 2.1	83 ± 52 ** min/day outdoors	31.0 ± 11.0	0.81
	Uncovered	36	22.3 ± 1.9 **	100	22.0 ± 3.1	49 ± 22 ** min/day outdoors	30.5 ± 11.6 ^^	
Meddeb et al. [27]	Covered	78	NA (20–60)	100	NA	NA	35.1	0.006 *
	Uncovered	183		100			42.5	
Gannagé-Yared et al. [28]	Covered	102	38.9 ± 5.8	100	27.3 ± 4.7	NA	13.0 ± 8.9	<0.001 **
	Uncovered	115	39.8 ± 5.4	100	24.3 ± 3.9		24.5 ± 16.25	
Dawodu et al. [29]	Covered Group A	33	23.6 ^ (18.5–28.7)	100	NA	1.94 * (0.61–6.21) h/week (geometric mean, back-transformed ± 1 log SD)	21.5 (11.3–43.5)	GrA vs. UC ^ <0.0001
	Covered Group B	25	25.8 ^ (19.6–32.0)	100		1.61 * (0.53–5.36) h/week (geometric mean, back-transformed ± 1 log SD)	31.5 (15.0–66.0)	GrB vs. UC ^ <0.0001
	Uncovered	17	32.7 ^ (28.5–36.9)	100		3.98 * (1.23–12.90) h/week (geometric mean, back-transformed ±1 log SD)	160.75 (122.5–210.8)	GrA vs. GrB 0.062

Vitamin D measurements provided in ng/mL were converted to nmol/L. Islam et al. report 30.5 ± 22.6 nmol/L for the uncovered group in the abstract and 30.5 ± 11.6 nmol/L in Table 1. Values from Table 1 were used. * Significance at $p < 0.05$. ** Significance at $p < 0.001$. ^ Significance at $p < 0.0001$. NA: not available. GrA = Group A. GrB = Group B. UC = Uncovered.

Of the eight studies, six reported a significant difference in serum 25(OH)D concentrations between the covered and uncovered groups, with lower levels in the former. Seven studies documented the percentage of vitamin D deficient participants in each group. However, various thresholds were applied to define VDD. In this review, the categories of vitamin D deficiency, insufficiency, and sufficiency were defined as 25(OH)D < 30 nmol/L, 30–50 nmol/L, and ≥50 nmol/L, respectively [30–32].

In the Karras et al. study, Christian Orthodox nuns were age- and diet-matched with women from the general population. Age and BMI were similar between the two groups; however, nuns reported significantly less weekly sun exposure than women in the general population group (4.23 vs. 11.2 h/week, p <0.01) [22]. The mean serum 25(OH)D concentrations were numerically lower in nuns than the comparator group, although the between-group difference did not reach statistical significance (56.16 ± 21.72 vs. 65.89 ± 22.71 nmol/L, p = 0.062). Data were collected between September 2023 and March 2024.

Buyukuslu et al. studied 100 female university students in Istanbul, Turkey, during April and May [23]. Mean serum 25(OH)D concentrations were significantly lower in covered participants than uncovered participants (52.8 ± 16.8 vs. 74.3 ± 7.8 nmol/L, p < 0.0001). Vitamin D deficiency or insufficiency was more common in covered participants than uncovered (55% vs. 20%, using the study-defined threshold of <50 nmol/L). The groups were similar in age, dietary intake, and sun exposure; however, covered participants had a slightly higher BMI than uncovered participants (24.0 ± 4.0 vs. 22.3 ± 3.1 kg/m^2, $p = 0.020$).

A study by Sayed-Hassan et al. studied 188 women in Damascus, Syria [24]. Samples were collected during summer and winter, defined as May-October and November-April, respectively. Covered participants had lower median serum 25(OH)D concentrations than uncovered participants (13.2 [10.0–21.6] vs. 17.1 [10.0–33.1] nmol/L, $p = 0.042$). Vitamin D deficiency was more common in covered participants than uncovered participants (82.3% vs. 65.3%, $p = 0.008$; OR 2.5, 95% CI 1.3–4.9, using the study-defined threshold of <25 nmol/L). The authors also reported that wearing a hijab was a significant predictor of vitamin D deficiency among women in univariate analysis. No seasonal difference in serum 25(OH)D was detected among women ($p = 0.54$). Regarding sun exposure, 61.2% of women spent ≤3 h per week outdoors, while 38.8% spent >3 h per week outdoors. These data were not stratified between covered and uncovered groups. All participants consumed a Middle Eastern diet with more than three servings of dairy a week.

The sole study that investigated men wearing traditional ultra-Orthodox clothing, where >90% of the body is covered, was conducted by Tsur et al. in Israel [25]. The study included three groups: two ultra-Orthodox groups wearing traditional attire (Yeshiva-A, largely indoors, n = 26; Yeshiva-B, with regular outdoor activity, n = 23) and one comparison group wearing conventional Western clothing (Yeshiva-C, n = 25). For the primary covered-versus-uncovered comparison, Yeshiva-A was used as the covered group, as Yeshiva-B differed from the other groups in both mean age (33.0 vs. approximately 20 years) and outdoor activity, confounding the clothing contrast. Mean serum 25(OH)D concentrations were significantly lower in covered participants than in uncovered participants (22.3 ± 9.0 nmol/L in Yeshiva-A, 25.5 ± 14.2 nmol/L in Yeshiva-B, vs. 54.2 ± 26.0 nmol/L in Yeshiva-C ($p < 0.05$, after adjustment for sun exposure). Covered participants had a lower sun exposure index than uncovered participants (18.2 ± 18.8 vs. 68.0 ± 30.6, $p < 0.001$). The sun exposure index was calculated based on a questionnaire regarding duration and degree of sun exposure and skin phototype. Sample collection occurred between March and April during spring. No data on dietary intake of calcium or vitamin D was recorded.

Islam et al. observed VDD in 30% of covered participants and 38.9% of uncovered participants in Bangladesh [26]. This study was conducted in summer (June–July); however, mean serum 25(OH)D concentrations were similar between covered and uncovered participants 31.0 ± 11.0 vs. 30.3 ± 11.6 nmol/L, $p = 0.81$, with both groups being only slightly above the study-defined threshold for VDD (<25 nmol/L). BMI was similar between the two groups, while age and sun exposure were significantly different. The mean age of the covered group was 47.7 years old vs. 22.3 years old for the uncovered group ($p < 0.001$). On average, covered women spent more time outdoors than uncovered women (83 ± 52 vs. 49 ± 22 min/day, $p < 0.001$). Information on dietary intake was not collected.

In the Meddeb et al. study, conducted in Tunisia, vitamin D insufficiency and deficiency (≤37.5 nmol/L) were observed in 70.5% of covered women and 48.9% of uncovered women ($p = 0.006$) [27]. Mean serum 25(OH)D concentrations were lower in covered women than uncovered women (35.1 vs. 42.5 nmol/L, $p = 0.006$). In women with serum 25(OH)D levels ≤ 37.5 nmol/l, the average duration of sun exposure was 2 h and 3 min, compared to 2 h and 30 min in women with >37.5 nmol/l. When samples were collected in winter (January–March), both groups were vitamin D insufficient. Ninety-two percent of participants consumed < 200 international units (IU) per day of dietary vitamin D.

Gannagé-Yared et al. reported severe VDD (<12.5 nmol/L) in 61.8% of covered women compared with 23.5% of uncovered women in Lebanon [28]. Mean serum 25(OH)D concentrations were lower in covered women than in uncovered women (13.0 ± 8.9 vs. 24.5 ± 16.25 nmol/L, $p < 0.001$). Data were retrieved in winter (January–April), and both groups fell into the VDD category, on average. Calcium dietary intake, age, and BMI were homogene across groups. Dietary intake of vitamin D was lower in covered women (74.4 ± 50.8 IU) than in uncovered women (99.7 ± 61.3 IU, $p = 0.001$).

A study by Dawodu et al. in Al Ain, UAE, compared two covered Arab groups with a European comparator group [29]. Covered group A (UAE nationals, n = 33) had more areas covered, with only the hands and feet exposed, while covered group B (non-Gulf Arabs, n= 25) had the face, hands and feet uncovered. The comparator group (n = 17) comprised European women resident in the UAE, who differed from both Arab groups by ethnicity and skin phototype as well as by dress. This study was completed in summer (June–September). Serum 25(OH)D concentrations were 21.5 nmol/L in covered group A, 31.5 nmol/L in covered Group B, and 160.75 nmol/L in the European group ($p < 0.0001$). The difference between the two covered groups did not reach significance ($p = 0.062$). Mean ages of the covered group A, covered group B, and uncovered group were 23.6, 25.8, and 32.7 years old, respectively ($p < 0.0001$). Total sunlight exposure differed only marginally across groups, whereas the clothing score (which quantifies exposed body surface area) differed markedly, as did the UV score (calculated as a product of clothing score and duration of exposure). In multivariable regression, serum 25(OH)D was independently associated with nationality ($p < 0.0001$), age ($p = 0.03$), clothing score ($p < 0.0001$) and UV score ($p < 0.0001$). Notably, nationality remained an independent predictor alongside the clothing and UV scores, indicating that the between-group difference is not attributable to clothing practice alone.

3.3. Quantitative Synthesis

Six of the eight included studies reported data permitting quantitative pooling. Two studies could not contribute to the quantitative synthesis. Meddeb et al. [27] reported group means without any measure of dispersion, and a mean difference cannot be pooled without a standard deviation. Dawodu et al. [29] reported geometric means back-transformed from natural logarithms, from which the arithmetic standard deviations required for pooling cannot be recovered without additional distributional assumptions. Both studies were therefore summarized narratively rather than pooled.

In random-effects meta-analysis, serum 25(OH)D was 12.8 nmol/L lower in covered than uncovered individuals (95% CI −21.7 to −3.8; $z = -2.79$, $p = 0.005$; Figure 2), with substantial heterogeneity ($I^2 = 93.7\%$; $\tau^2 = 113.2$; $Q = 52.5$, df = 5, $p < 0.001$). The 95% prediction interval was −35.5 to +9.9 nmol/L. Individual study estimates ranged from −31.9 nmol/L (Tsur et al. [25]) to +0.5 nmol/L (Islam et al. [26]), with five of six favouring lower 25(OH)D in covered individuals. Leave-one-out analysis did not alter the direction or statistical significance of the pooled estimate in any iteration. Pre-specified sensitivity analyses excluding Sayed-Hassan et al. [24] (means estimated from medians) and Islam et al. [26] (mean age difference of 25.4 years between groups) yielded pooled mean differences of −14.5 nmol/L (95% CI −24.9 to −4.0) and −15.4 nmol/L (95% CI −24.3 to −6.6) respectively; excluding both yielded −18.2 nmol/L (95% CI −27.5 to −9.0; $I^2 = 87.9\%$). Small-study effects were not formally assessed, as fewer than ten studies were available.

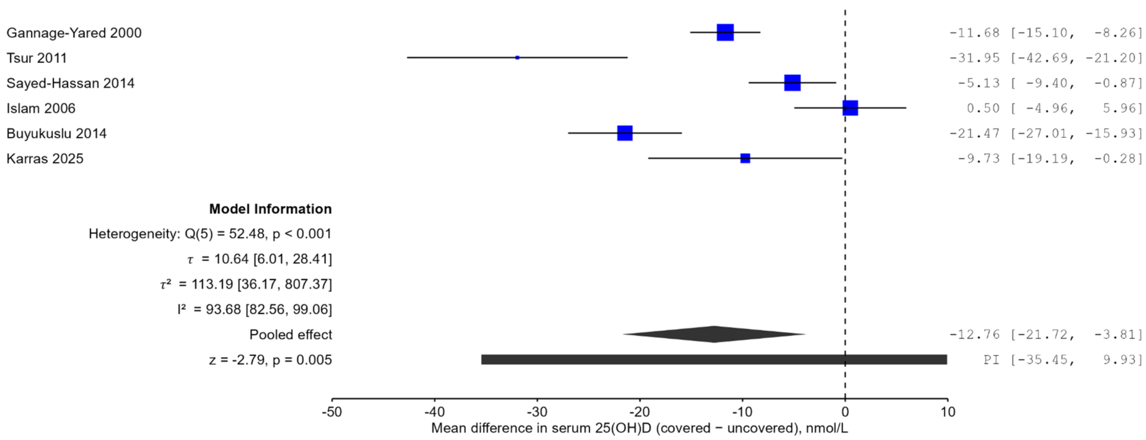

Figure 2. Forest plot of the random-effects meta-analysis of the mean difference in serum 25(OH)D (covered minus uncovered), in nmol/L, for the six pooled studies [22–26, 28]. Squares represent individual study point estimates, with the marker size proportional to the study weight; horizontal lines indicate 95% confidence intervals (CI). The vertical dashed line marks the line of no effect (0 nmol/L). The diamond represents the pooled random effects estimate, and the bar labelled “PI” indicates the 95% prediction interval. Study-level mean differences with 95% CIs are listed at the right, and heterogeneity statistics (Q, τ^2, I^2) are shown at the lower left. 25(OH)D = 25-hydroxyvitamin D.

3.4. Risk of Bias

Newcastle-Ottawa scores ranged from 4 to 8 out of 10 (Table 3), with three studies rated good, four fair, and one poor. Representativeness and lack of detail regarding non-respondents were the most common weaknesses. Seven of the eight studies selected particular groups of users and did not mention non-respondents. Control of confounding was another weakness. Karras et al. [22], Tsur et al. [25], Islam et al. [26] and Dawodu et al. [29] compared groups differing in sun exposure. Islam et al. [26] and Dawodu et al. [29] featured groups with different mean ages without adjustment. Assay platforms also varied across studies (radioimmunoassay, enzyme-linked immunosorbent assay, electrochemiluminescence, and high-performance liquid chromatography), a recognized source of between-study variation in measured 25(OH)D.

Table 3. Risk of bias and methodological quality of included studies (Newcastle-Ottawa Scale adapted for cross-sectional studies [18]).

Study	Representativeness (1)	Sample Size (1)	Non-Respondents (1)	Ascertainment of Exposure (2)	Comparability (2)	Outcome Assessment (2)	Statistical Test (1)	Total/10	Quality
Sayed-Hassan et al. [24]	–	★	★	★	★★	★★	★	8	Good
Meddeb et al. [27]	★	★	–	★	★	★★	★	7	Good
Gannagé-Yared et al. [28]	–	★	–	★	★★	★★	★	7	Good
Karras et al. [22]	–	–	–	★	★	★★	★	5	Satisfactory
Buyukuslu et al. [23]	–	–	–	★	★	★★	★	5	Satisfactory
Tsur et al. [25]	–	–	–	★	★	★★	★	5	Satisfactory
Dawodu et al. [29]	–	–	–	★★	–	★★	★	5	Satisfactory
Islam et al. [26]	–	–	–	★	–	★★	★	4	Unsatisfactory

★ = one star (point) awarded for meeting criterion in that domain; ★★ = two stars awarded for meeting preferred criterion in a domain with multiple criteria (maximum of two stars for that domain); – = criterion not met. Maximum score: 10 stars across three domains (Selection, 5; Comparability, 2; Outcome/Statistical Test, 3). Quality categories: Good—7–10, Satisfactory—5–6, Unsatisfactory—0–4.

4. Discussion

To our knowledge, this is the first systematic review and meta-analysis to examine the association between vitamin D status and body-covering clothing practices in healthy, asymptomatic adults aged 18–65, excluding individuals who are pregnant, smokers, or taking supplements or medications affecting vitamin D metabolism. Across six studies, body-covering garments were significantly associated with lower mean serum 25(OH)D levels, with differences ranging from 3.9 to 139.25 nmol/L. One study reported a non-significant 25(OH)D reduction with traditional attire, while another study found no difference in 25(OH)D levels. The reasons for these findings warrant consideration.

Islam et al. found comparable 25(OH)D levels in covered and uncovered Bangladeshi women (31.0 vs. 30.3 nmol/L; $p = 0.81$) [26], but the comparison is difficult to interpret because the exposure gradient ran counter to expectation: the covered group reported substantially more daily outdoor time than the uncovered group (83 ± 52 vs. 49 ± 22 min/day; $p < 0.001$). The uncovered comparators were affluent university students who, as the authors note, spent very little time in direct sunlight, potentially directly counteracting the expected clothing effect. Vitamin D insufficiency was near universal across all groups (78–83% at below 40 nmol/L). The comparison therefore contrasted two differently sun-deprived populations rather than exposed with unexposed skin. It reflects the failure of the comparison group to serve as an adequate unexposed control rather than evidence against an effect of clothing on vitamin D status.

Karras et al. reported a trend toward lower 25(OH)D in Orthodox nuns compared with laywomen practicing intermittent fasting (22.5 vs. 26.4 ng/mL; $p = 0.062$), despite the laywomen having significantly greater weekly sun exposure (11.2 vs. 4.23h/week; $p < 0.01$) [22]. As with Islam et al. [26], this finding requires careful interpretation. The study was not designed to detect between-group differences in 25(OH)D; its primary objective was identifying within-group predictors of vitamin D status, and no sample size calculation was performed around this comparison. The trend should therefore be read as hypothesis-consistent rather than definitive. Additionally, raw sun exposure hours do not capture effective cutaneous UVB dose; given the near-total body coverage of traditional religious attire, the functional difference in UV exposure between groups almost certainly exceeds what self-reported duration reflects. The more compelling between-group finding may be the parathyroid hormone (PTH) concentrations, which were nearly double in the nuns (42.0 vs. 24.6 pg/mL; $p < 0.01$). Elevated PTH may reflect vitamin D and calcium homeostatic stress [33], and its magnitude here suggests a meaningful biological burden not fully reflected by 25(OH)D alone. That said, the Athonian fasting practiced by the nuns may also lead to dietary drivers of PTH elevation; hence, in this cross-sectional study, the contribution of clothing-restricted UV exposure and fasting-related dietary deficiency to the observed PTH difference cannot be separated.

A related systematic review and meta-analysis preprint by Mohamed et al. investigated "concealing clothes" and vitamin D levels in healthy adult women [16]. However, of the 14 included studies, several involved children, adolescents, supplement use, smokers, or peri-partum patients, or lacked complete outcome data. Notably, the review has not undergone peer review. Mohamed et al. reported that covered women had 2.28 times greater odds of vitamin D deficiency (<50 nmol/L) than uncovered women ($p < 0.001$). As of 2026, this paper is still in its preprint status.

Although excluded from our final analysis due to supplement use in over half of the participants, a Canadian study by Ojah and Welch in Halifax, Nova Scotia, is worth noting [34]. In a matched-pair design comparing seven women who wore hijab and seven women in "Western" attire, the covered group had significantly lower 25(OH)D levels (40 ± 28 vs. 81 ± 32 nmol/L, $p = 0.01$). While Halifax (43° N) lies approximately 10° south of Edmonton (53° N), it experiences higher cloud cover and fog, potentially affecting UVB availability [14,34].

4.1. Vitamin D Deficiency in the Canadian Context

In Canada, VDD is a significant public health issue: a 2010 study demonstrated that 14–60% of Canadians were vitamin D deficient (using threshold values of 25–40 nmol/L), depending on the population group, season, and location [35]. Genuis et al. further reported a 16.75% VDD prevalence among those living in Edmonton, Alberta, with only 32% having 'adequate' 25(OH)D levels [36]. Given Canada's northern latitude and long winters, populations residing in Canada are at increased baseline risk of VDD, even in the absence of additional modifying factors.

Geographic latitude and climate are key determinants of cutaneous vitamin D synthesis. Canada lies farther north (average population-weighted latitude approximately 45.7° N) than most of the countries where the included studies were conducted, such as Greece, Turkey, Syria, Israel, Bangladesh, Tunisia, Lebanon, and the UAE, which fall between approximately 24° N and 39° N [15,37]. UVB radiation required for vitamin D production is markedly reduced at higher latitudes, particularly during fall and winter, when the solar zenith angle limits the intensity and duration of UVB reaching the skin [38].

Studies have shown that no appreciable vitamin D synthesis occurs in locations like Edmonton, London (52° N) or Boston, Massachusetts (42.4° N) from November through February due to insufficient UVB radiation [14]. Edmonton, Alberta is located at approximately 53.5° N, further emphasizing the challenge of vitamin D synthesis in Canada's higher latitudes. Above 33° N, vitamin D production in the skin is negligible during winter months [15]. In contrast, sunnier countries like Israel and the UAE benefit from arid or semi-arid climates, longer days, and clearer skies, which contribute to more consistent year-round UVB exposure, even among those who wear modest clothing [1,14].

4.2. Modest Clothing and Its Implications

This review explores the impact of modest, body-covering clothing practices and vitamin D levels. Such attire is worn for a range of reasons, including religious observance, cultural identity, tradition, and personal choice. Several studies identified in this review showed higher risks of vitamin D insufficiency or deficiency among individuals who wear body-covering clothing, even in sun-rich regions. These findings are especially relevant in Canada, where UVB exposure is already limited due to northern latitude, weather patterns, and seasonal behaviors. In such settings, modest clothing becomes one of several compounding environmental and behavioral factors that may further reduce endogenous vitamin D production, reinforcing the need for culturally respectful strategies to support vitamin D sufficiency in affected communities.

4.3. Skin Type as a Biological Modifier

Vitamin D synthesis varies significantly by skin type, even under similar geographic and behavioral conditions. Individuals with darker skin (Fitzpatrick Skin Type [FST] V–VI) have more epidermal melanin, which absorbs UVB radiation and reduces cutaneous vitamin D production compared to lighter skin types (FST I–IV) [39]. Although melanin provides photoprotection, it raises the threshold of UVB exposure needed for sufficient vitamin D synthesis.

In Greater Manchester, UK (latitude 53.5° N), comparable to Edmonton, Alberta, Canada, Webb et al. estimated that white Caucasian participants (FST I–II) needed approximately 9–13 min of midday sun exposure daily from March to September to maintain winter serum 25(OH)D levels ≥ 25 nmol/L, assuming 35% body surface area exposure (equivalent to wearing a short-sleeve t-shirt and shorts) and no sunscreen [40]. In contrast, South Asians (FST V) required 25–40 min under identical conditions [41].

Kift et al. further reported that over 90% of South Asian adults (FST V) in Greater Manchester were vitamin D deficient, versus only 5% of white Caucasians [42], highlighting the significant impact of skin pigmentation on vitamin D status, even in the same environment.

Notably, the ≥25 nmol/L threshold used in Webb et al.'s study aligns with UK guidelines, whereas Canadian health authorities recommend ≥50 nmol/L for sufficiency [41]. Reaching this higher target would likely require longer or more extensive sun exposure, particularly for individuals with darker skin living at northern latitudes, which may not be practically feasible.

4.4. Intersectionality: Cultural Practices, Skin Type, and Latitude

A clear example of intersecting risk factors may be seen among some Muslim women living in Canada. This population is diverse; however, some individuals may face compounded risk of VDD due to (1) reduced UVB availability at northern latitudes, (2) the use of modest clothing limiting skin exposure, and (3) higher melanin content associated with FST III–VI, which is more prevalent in some of the ethnic communities represented within Canada's Muslim population, including those of South Asian (37.6%), Arab (32.2%), West Asians (13%), and Black (11.6%) descent [9,39,43–46]. The additive effect of these risk factors suggests that, without targeted public health guidance, some individuals may be at higher risk for vitamin D insufficiency.

4.5. Impact of Age and BMI

Two studies comparing covered and uncovered groups reported significantly higher mean ages in the covered groups, by 25.4 and 9.1 years [26,29]. While Islam et al. found similar serum 25(OH)D levels between groups, Dawodu et al. reported significantly lower levels in covered women [26,29]. Age is a known modifier of vitamin D synthesis, as the skin's concentration of 7-dehydrocholesterol, the precursor to vitamin D, declines with age [47]. Chalcraft et al. showed a 13% reduction in vitamin D synthesis per decade of age [48]. Thus, older age may confound or partially explain the relationship between modest clothing and lower 25(OH)D levels.

Of the eight studies reviewed, one reported a significantly higher BMI in covered participants, who also had lower 25(OH)D levels [23]. Obesity is negatively associated with vitamin D status due to the lipophilic nature of 25(OH)D, which leads to its sequestration in adipose tissue and reduced bioavailability [49,50]. This variation in BMI represents another confounding factor when assessing the effect of modest clothing on vitamin D status, and the lower 25(OH)D levels in this study in covered participants could be attributed to their higher BMI.

Other important factors that affect vitamin D synthesis and UVB exposure include urban residence, air pollution, diet, vitamin D intake, lifestyle, indoor schooling and employment, physical activity, smoking, renal and hepatic function, PTH level, sunscreen use and additional sun protection behaviors [1,3,6,24,25,28,33,51–54].

4.6. Health Implications of Vitamin D Deficiency

VDD is a recognized global health concern associated with a wide spectrum of adverse outcomes, including rickets in children, osteoporosis in adults, and increased risk of various chronic diseases. It has been associated with multiple cancers, including breast, ovarian, colorectal, melanoma, and squamous cell carcinoma, as well as cardiovascular conditions such as hypertension, heart failure, and atherosclerosis, with proposed protective mechanisms including anti-inflammatory activity, myocardial regulation, and modulation of the renin-angiotensin system [55–58]. Autoimmune and metabolic associations include multiple sclerosis, systemic lupus erythematosus, rheumatoid arthritis, type 2 diabetes, and metabolic dysfunction-associated fatty liver disease, with VDD thought to impair insulin synthesis and increase insulin resistance [59–64]. Mental health associations, including depression, anxiety, schizophrenia, and reduced academic performance, have been reported across multiple age groups, including adolescents and children [65–68]. In pregnancy, VDD is associated with gestational diabetes, preeclampsia, cesarean delivery, preterm birth, low birth weight, and postpartum depression, and deficiency commonly persists in both mothers and newborns despite standard supplementation [3,69–71].

These far-reaching associations underscore the importance of targeted prevention in groups at elevated risk of VDD. In Canada, individuals who wear modest clothing, including many Orthodox Christians, Muslim women, and members of the ultra-Orthodox Jewish community, may face compounded risk from reduced UVB exposure at northern latitudes and, for some, the additional biological modifier of higher skin melanin content. These risks may be further shaped by social determinants of health: some Muslim women in Canada may face intersecting barriers including systemic healthcare inequities and employment discrimination [72–74], while ultra-Orthodox Jewish communities may encounter structural barriers to care and mental health stigma [75–79]. Addressing VDD in these communities is an important component of equitable, preventive care.

4.7. Guidelines for Vitamin D Supplementation

Recommendations for daily vitamin D intake vary across countries, ranging from 400 to 2000 IU [69,80]. In Canada, Europe, and the US, current guidelines recommend 600 IU of daily vitamin D for healthy adults up to 70 years old, including pregnant individuals, to prevent VDD [81,82]. A variety of adult multivitamins are sold in Canada and may contain 400–1000 IU of vitamin D. The majority of prenatal vitamins only contain 400 IU [81]. Thus, additional consumption of vitamin D may be required for some pregnant women and may also be necessary for other populations through sunlight exposure, dietary sources, or more supplementation.

Given the heightened risk of VDD among covered populations and those living in northern climates, targeted interventions, such as vitamin D supplementation and public health campaigns promoting safe sun exposure, are essential strategies to mitigate adverse health outcomes. Schwalfenberg et al. further emphasized the need for targeted public health interventions to address widespread vitamin D deficiency in Canada [35].

4.8. Limitations

This review has several limitations. The number of studies meeting inclusion criteria was small (n = 8), and all utilized a cross-sectional design, precluding any inference about causality. Small-study effects could not be formally assessed with fewer than ten pooled studies. Most included studies were conducted in sun-rich regions where UVB exposure is available year-round, limiting the direct applicability of findings to high-latitude countries such as Canada, where seasonal UVB is significantly reduced.

Seven of eight studies focused exclusively on women, and all studies enrolled healthy adults, leaving the association in men and in people with chronic illness or other co-existing risk factors largely unexamined.

Covered and uncovered groups differed in mean age, BMI, or sun exposure in several studies, each an independent determinant of vitamin D status, and "modest clothing" spanned a wide range of coverage whose degree of UVB attenuation was not captured consistently. Sun exposure was also measured using non-interchangeable constructs across studies.

Fitzpatrick skin phototype was not reported at the group level in any study and could not be tabulated, so residual confounding by pigmentation is possible. Its likely magnitude is limited by the within-country design of most comparisons, in which covered and uncovered participants were drawn from broadly similar populations; the exception is Dawodu et al. [29], whose comparator group differed by ethnicity as well as dress. Fitzpatrick phototype is in any case a weak proxy for effective cutaneous UVB dose when behavioural and sartorial exposure differ substantially, which may contribute to the clinical observation that deficiency is common in Middle Eastern patients whose skin appears comparatively light.

Heterogeneity in the pooled estimate was substantial (I^2 = 93.7%), as anticipated given variation in body coverage, latitude, season, and assay. The pooled mean difference should therefore be read as an average across heterogeneous exposures rather than a single transportable effect, though the direction of effect was consistent in five of six studies and no single study drove the result.

Finally, fully independent duplicate extraction was not performed; this is acknowledged as a limitation. While resource constraints precluded dual independent screening, standardized eligibility criteria and predefined data extraction forms were used throughout the review to promote consistency. In addition, the review was not prospectively registered, and a protocol was not prepared.

4.9. Recommendations for Future Research and Public Health Strategies

While the current body of literature demonstrates a consistent association between modest clothing and lower vitamin D levels, further research is needed to inform evidence-based interventions. Longitudinal and interventional studies should be conducted in northern climates like Canada, accounting for variations in skin phototype, sun exposure, and seasonal behavior. Future research should also aim to include male participants and populations with chronic health conditions to better understand the broader implications.

Public health strategies must be respectful and inclusive, promoting vitamin D sufficiency through supplementation, dietary recommendations, and education, without discouraging religious, cultural, or traditional clothing practices. Recommendations should be personalized and culturally sensitive, reflecting the diversity of communities in Canada. Clear guidelines adapted for different seasons, skin phototypes, and clothing habits would support equitable and respectful care.

5. Conclusions

Modest, body-covering clothing is one of several interacting factors that may reduce cutaneous vitamin D synthesis, and its clinical significance is likely greatest in settings where ambient UVB is already limited, a context directly applicable to Canada. Across the majority of included studies, body-covering garments were associated with meaningfully lower serum vitamin D levels, even in sun-rich environments. For communities where modest dress is practiced at northern latitudes, proactive vitamin D education, dietary strategies, supplementation, and culturally informed clinical screening represent practical, respectful strategies that support health without requiring any change to cultural or religious practice. Future research should prioritize longitudinal studies in northern-climate populations, with adequate attention to skin phototype, seasonal behavior, and inclusion of both male and female participants.

Supplementary Materials

The additional data and information can be downloaded at: https://media.sciltp.com/articles/others/2609151519017924/DSS-26060250-SI.zip. PRISMA 2020 Checklist, PRISMA 2020 Abstract Checklist [17].

Author Contributions

W.B.: conceptualization, methodology, data curation, writing—original draft preparation, editing; L.A.: contributed to manuscript review and editing, validation, and critical manuscript revision; E.Y.C.: conceived the study, data curation, statistical analysis, supervised the project, performed substantive manuscript revisions and literature integration, and reviewed and edited the manuscript. All authors have read and agreed to the published version of the manuscript.

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Informed Consent Statement

Informed consent was not required because this study did not involve direct participation by human subjects.

Data Availability Statement

All relevant data supporting the findings are included within the article.

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Conflicts of Interest

The authors declare no conflicts of interest.

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