

Tinted vs Nontinted Sunscreens: Attenuation of Near-Visible UVA and Visible Light and Implications for Skin of Color

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PRACTICE POINTS

- There is substantial variability in spectral attenuation among tinted sunscreens, highlighting the need for standardized pigment metrics and evidence-based photoprotection guidance for individuals with skin of color (SOC).
- Broad-spectrum labeling, sun protection factor values, UV filter type (mineral vs chemical), and antioxidant inclusion do not reliably predict protection against pigment-inducing UV and visible light wavelengths for individuals with SOC.
- Iron oxide-containing tinted sunscreens demonstrate lower near-visible UVA and blue light transmittance than nontinted formulations, with greater attenuation in mineral vs chemical products. Both pigment and filter type should inform photoprotection recommendations in individuals with SOC.

Individuals with skin of color (SOC) are disproportionately affected by hyperpigmentation disorders such as melasma and postinflammatory hyperpigmentation following sun exposure. Although epidermal melanin provides UVB protection, susceptibility to pigmentary responses from longer UVA wavelengths and visible light (VL) remains, particularly the highest energy wavelengths of blue light (BL) between 400 and 450 nm.¹ Blue light can induce immediate and persistent pigment darkening in those with Fitzpatrick skin types IV to VI, and trace amounts of near-visible UVA (NV-UVA) between 370 and 400 nm can synergize with VL to amplify pigmentation and erythema responses.²

Current photoprotection recommendations emphasize sun protection factor (SPF) ratings of 30+ and broad-spectrum labeling; however, under the US Food and Drug Administration standards, the broad-spectrum designation is based solely on achieving a mean critical wavelength of 370 nm or higher, which does not ensure meaningful attenuation of NV-UVA or VL wavelengths.³ Tinted sunscreens containing iron oxides (FeO) have been shown to improve protection against these pigment-inducing wavelengths,⁴ yet quantitative comparisons between tinted and nontinted commercial sunscreen products remain limited.

To address the gap in understanding about tinted vs nontinted commercial sunscreen products, we conducted an *in vitro* spectrophotometric comparative analysis. The objectives were to quantify NV-UVA and BL attenuation across products and evaluate whether formulation characteristics (eg, SPF rating, filter types and concentration, the presence and depth of tint, antioxidant content) would correlate with improved photoprotection in pigment-sensitive wavelengths. We hypothesized that formulation features such as higher SPF, inorganic filters, and the presence of tint antioxidants would be associated with superior NV-UVA and BL attenuation compared with nontinted formulations.

Methods

Sunscreen Selection—A convenience sample of 23 broad-spectrum sunscreens commercially available at drugstores was selected to reflect easily accessible options. Six sunscreen brands with tinted (n=13) and nontinted (n=10) counterpart formulations were included.

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The eFigures and eTables are available in the Appendix online at mededge.com/cutis.

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Filter category (mineral and/or chemical), SPF, UV filter type and concentration, tint shade (light, medium, medium/deep, deep), number of photoprotective antioxidants (diethylhexyl syringylidenemalonate, vitamin E, vitamin C, licochalcone A, and glycyrrhetic acid), and presence of FeO were recorded.

Substrate Preparation—Testing was performed using standardized polymethyl methacrylate (PMMA) plates. Sunscreens were mixed prior to application and applied at 1.3 mg/cm² per the European Cosmetic and Perfumery Association (COLIPA) UVA testing guidelines.⁵ Plates were reweighed to confirm dosing and dried in a dark environment for at least 15 minutes prior to testing.

Spectrophotometric Measurements—Spectral transmittance was measured from 250 to 450 nm using a spectrophotometer equipped with a xenon flash lamp (energy <0.2 J/cm²). Baseline transmission was recorded using untreated PMMA plates. Five scans were averaged per plate. Analyses focused on NV-UVA transmittance from 380 to 400 nm and peak BL transmission at 450 nm.

Mean NV-UVA transmittance was calculated as the arithmetic mean of percent transmittance measured at 1-nm increments from 380 to 400 nm (n=21). Because of the steep rise in transmittance between 380 and 400 nm and subsequent plateau into the visible range, this approach was used to approximate the area under the transmittance-wavelength curve over the specified interval, enabling direct comparison of NV-UVA penetration between formulations.

Statistical Analysis—Descriptive statistics were used to summarize transmittance values. Spearman rank correlation was used to assess associations between formulation variables and spectral attenuation. Analysis of covariance was used to evaluate the effect of FeO on transmittance while adjusting for SPF or filter type. The Mann-Whitney U test was used to compare NV-UVA and blue light transmittance between FeO-containing mineral and chemical formulations. Statistical significance was set at $P < .05$.

Results

Across broad-spectrum sunscreen formulations (N=23), mean SPF values were 40.4 (range, 30-70), and the mean number of antioxidants in the ingredient list was 1.5 (range, 0-4). Mean NV-UVA transmittance was 16.7% (range, 0.1%-55.0%) and mean BL transmittance was 44.3% (range, 0.3%-97.5%) (eTable 1).

The mean labeled zinc oxide (ZnO) concentration among ZnO-containing formulations (n=14) was 10.5% (range, 5.0%-21.6%), with mean NV-UVA and BL transmittance of 12.6% (range, 0.1%-55.0%) and 25.8% (range, 0.3%-67.2%), respectively. Mean NV-UVA and BL transmittance were 26.7% (range, 9.6%-55.0%) and 45.6% (range, 23.0%-67.2%) among ZnO formulations without FeO (n=5), compared with lower transmittance of 4.8% (range, 0.1%-11.5%) and 14.9% (range, 0.3%-29.5%) in ZnO formulations containing FeO (n=9).

The mean labeled titanium dioxide (TiO₂) concentration among TiO₂-containing formulations (n=14) was 9.0% (range, 3.2%-17.0%), with corresponding mean NV-UVA and BL transmittance of 9.5% (range, 0.1%-28.5%) and 22.7% (range, 0.3%-47.6%), respectively. Among TiO₂ formulations without FeO (n=4), mean NV-UVA and BL transmittance was 19.7% (range, 9.6%-28.5%) and 39.8% (range, 23.0%-47.6%), while FeO-containing TiO₂ formulations (n=10) showed lower mean NV-UVA and BL transmittance of 5.4% (range, 0.1%-11.5%) and 15.8% (range, 0.3%-29.5%), respectively.

The mean labeled avobenzone concentration among avobenzone-containing formulations (n=8) was 2.9% (range, 2.5%-3%), with mean NV-UVA and BL transmittance of 24.7% (range, 10.2%-46.6%) and 79.2% (range, 53.9%-97.5%). Formulations without FeO (n=5) had mean NV-UVA and BL transmittance of 29.0% (range, 10.2%-46.6%) and 83.2% (range, 61.1%-97.5%), whereas FeO-containing products (n=3) demonstrated lower mean NV-UVA and BL transmittance of 17.5% (range, 12.5%-21.9%) and 72.6% (range, 53.9%-85.1%), respectively.

Among products containing ZnO, TiO₂, and avobenzone, the specific UV filter concentrations showed no statistically significant correlation with NV-UVA or BL transmittance (all $P > .05$). Iron oxide presence significantly correlated with lower NV-UVA ($r = -0.67$; $P = .00042$) and lower BL transmittance ($r = -0.57$; $P = .0046$). The number of antioxidants in the ingredient list did not correlate with NV-UVA transmittance ($r = -0.28$; $P = .19$) or BL transmittance ($r = -0.16$; $P = .47$). Sun protection factor was not significantly correlated with either wavelength range (Table 1).

Tint shade was treated as an ordinal variable (light, medium, medium/deep, and deep; medium was considered the universal shade). Increasing tint shade depth was significantly associated with reduced NV-UVA ($r = -0.64$; $P = .045$) and BL ($r = -0.71$; $P = .023$), suggesting a dose-response relationship wherein darker tints exhibited greater attenuation of pigment-relevant wavelengths. Among mineral filter formulations, tinted products demonstrated lower NV-UVA and BL transmittance compared with their nontinted counterparts, with deeper tints providing the greatest reduction in transmittance (eFigure 1). Similar results were observed for chemical filter formulations with greater attenuation in the NV-UVA and BL range for tinted versus nontinted products with greater variability across shade depths (eFigure 2).

After adjusting for SPF, FeO presence remained significantly associated with reduced NV-UVA ($F[1,20] = 26.9$; $P < .001$) and BL transmittance ($F[1,20] = 11.7$; $P = .003$). After adjusting for filter type (mineral vs chemical), FeO remained significantly associated with NV-UVA ($F[1,19] = 10.1$; $P = .004$) and BL transmittance ($F[1,19] = 10.4$; $P = .005$) (Table 2).

Among FeO-containing products, mineral filters demonstrated significantly lower NV-UVA transmittance compared with chemical filters (median, 5.58%

TABLE 1. Associations Between Formulation Variables and NV-UVA and Peak Blue Light Transmittance

| Variable | NV-UVA transmittance (380-400 nm) | BL transmittance (450 nm) |
|---|-----------------------------------|---------------------------|
| ZnO concentration | $r=-0.25, P=.39$ | $r=-0.13, P=.65$ |
| TiO ₂ concentration | $r=-0.25, P=.39$ | $r=-0.42, P=.13$ |
| Avobenzone concentration | $r=-0.19, P=.67$ | $r=-0.33, P=.43$ |
| Iron oxide presence | $r=-0.67, P=.00042$ | $r=-0.57, P=.0046$ |
| No. of antioxidants in ingredients list | $r=-0.28, P=.19$ | $r=-0.16, P=.47$ |
| SPF | $r=0.08, P=.70$ | $r=0.02, P=.93$ |
| Tint shade (mineral products) | $r=-0.64, P=.045$ | $r=-0.71, P=.023$ |

Abbreviations: BL, blue light; NV-UVA, near-visible UVA; SPF, sun protection factor.

[interquartile range (IQR), 0.59%-9.35%] vs 18.10% [IQR, 12.47%-21.90%]; $U=0.00$; $P=.007$). The same was true for BL transmittance (median, 15.90% [IQR, 5.00%-26.20%] vs 78.70% [IQR, 53.90%-85.10%]; $U=0.00$; $P=.007$). The differences in spectral transmittance between FeO-containing mineral and chemical filter formulations are illustrated in eFigure 3, with mineral-based products demonstrating lower transmittance, particularly across the upper NV-UVA range and across the BL range. These results indicated greater pigment-relevant photoprotection with mineral vs chemical filters (eTable 2).

Comment

Our initial hypothesis proposed that tinted sunscreens would provide greater NV-UVA and BL attenuation than nontinted formulations, and that characteristics such as inorganic filter content, SPF rating, and antioxidants would correlate with improved protection in pigment-sensitive wavelengths. Our findings partially supported this hypothesis. In this analysis, substantial variability in the NV-UVA and BL transmittance was observed despite all products meeting broad-spectrum criteria. Nontinted mineral and chemical sunscreens exhibited high transmittance in these pigment-related wavelengths, reaching values as high as 55.0% for NV-UVA and 97.5% for BL. These findings align with prior analysis demonstrating that while broad-spectrum sunscreens available in the United States may meet the current critical wavelength criteria for protection in the UVA range, they still may transmit 30% to 66% of available UVA over 2 hours between formulations with equivalent SPF label values.⁶

Recent analyses show that sunscreen recommendations in lay media rarely incorporate input from board-certified dermatologists for individuals with SOC and disproportionately favor nontinted chemical formulations,

despite the high prevalence of pigmentary disorders in this population.⁷ Near-visible UVA and BL have been demonstrated to be biologically relevant pigment-inducing wavelengths, both in vitro and in vivo, particularly in individuals with SOC, yet broad-spectrum labeling does not ensure protection against these spectra.⁸ Pigmentary tints such as FeO have demonstrated enhanced attenuation in this spectral region in vivo and may provide more reliable coverage than products with broad-spectrum designation alone.^{4,9} Treatment options for pigmentary disorders such as melasma tend to be palliative and costly, making optimized photoprotection a critical component of care to reduce ongoing pigmentary stimuli.¹⁰

Formulations containing FeO demonstrated significantly lower NV-UVA ($P<.001$) and BL transmittance ($P=.003$) on average; however, transmittance values ranged widely (NV-UVA: 0.10%-21.90%, BL: 0.30%-85.10%), indicating that FeO presence alone does not determine the magnitude of attenuation. Notably, among FeO-containing products, mineral filters provided significantly lower NV-UVA and BL transmittance compared with chemical filters ($P=.007$ for both), suggesting that filter type further modulates pigment-relevant photoprotection. Tinted formulations may improve compliance with product use by reducing the white cast and improve shade matching to find suitable options for deeper skin tones,¹¹ but the highly variable photoprotection offered raises concerns about clinical benefit. Although deeper tints showed greater attenuation, pigment concentrations and combinations are not disclosed by manufacturers as FeO is not considered an active ingredient. Darker shades are not practical across all skin tones in individuals with SOC, which underscores the need for standardized pigment metrics and shade-inclusive options.

While avobenzone and ZnO are the only US Food and Drug Administration–approved sunscreen active

TABLE 2. Associations Between FeO Content and NV-UVA (380-400 nm) and Peak Blue Light (450 nm) Transmittance

| Model | F statistic (df ₁ , df ₂) | P value |
|-------------------|--|---------|
| SPF (adjusted) | | |
| NV-UVA | $F(1, 20)=26.9$ | <.001 |
| BL | $F(1, 20)=11.7$ | .003 |
| Filter (adjusted) | | |
| NV-UVA | $F(1, 19)=10.1$ | .004 |
| BL | $F(1, 19)=10.4$ | .005 |

Abbreviations: BL, blue light; df, degrees of freedom; FeO, iron oxide; NV-UVA, near-visible UVA; SPF, sun protection factor.

ingredients that extend protection beyond 360 nm,¹² both exhibited reduced attenuation beyond the longer end of the UVA spectrum. Formulation characteristics, including the concentration of ZnO, TiO₂, and/or avobenzone as well as SPF, did not correlate with NV-UVA or BL attenuation. In the adjusted analysis, FeO presence remained significantly associated with reduced transmittance after adjusting for SPF (NV-UVA: $P<.001$, BL: $P=.003$) or filter type (NV-UVA: $P=.004$, BL: $P=.005$). These findings suggest that the presence of FeO, rather than UV filters or SPF ratings, supports attenuation in the 380 to 450-nm range, indicating a functional benefit in addition to improved cosmesis.¹³

Although antioxidants in specific combinations have shown promise in vivo, no association was observed between the number of antioxidants present and NV-UVA or BL attenuation compared with added tint.¹⁴ This suggests that specific antioxidant combinations and their concentrations may be more relevant than the total count.

Several study limitations need to be considered in interpreting our results, including a modest number of products, controlled in vitro testing conditions, and an incomplete representation of products with pigment concentrations and shade ranges marketed to individuals with SOC across all price categories, despite our focus on affordable, commercially available options. Moreover, PMMA-based spectrophotometry does not account for skin surface heterogeneity, photodegradation, sweat, oil, friction, or application variability, which may alter real-world performance. Additionally, FeO concentrations could not be quantified beyond labeling of tint shade depth, preventing a true assessment of dose-response effects. These limitations may reduce generalizability and highlight the need for complementary in vivo studies to assess clinically relevant outcomes such as persistent pigment darkening. For this reason, caution is warranted in extrapolating these spectral findings to clinical efficacy.

Conclusion

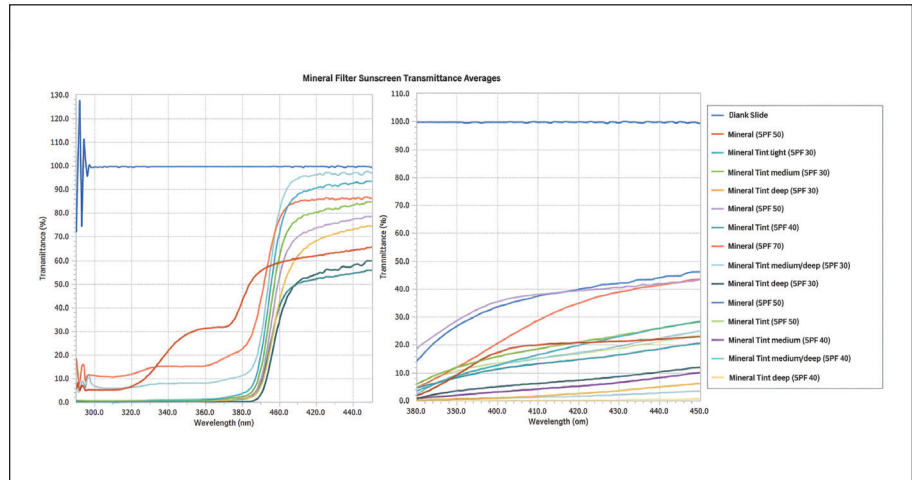
Given the susceptibility of individuals with SOC to pigmentary disorders driven by NV-UVA and BL, our findings support further development and study of FeO-containing sunscreens that address clinically relevant wavelengths. Wide variability in photo-attenuation among tinted formulations underscores the need for evidence-based recommendations, with further studies needed to guide photoprotection strategies for populations with SOC.

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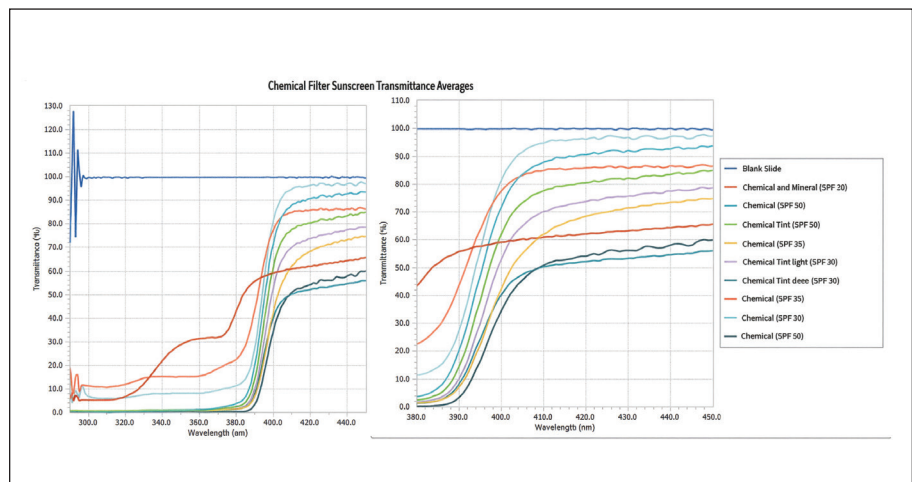
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APPENDIX

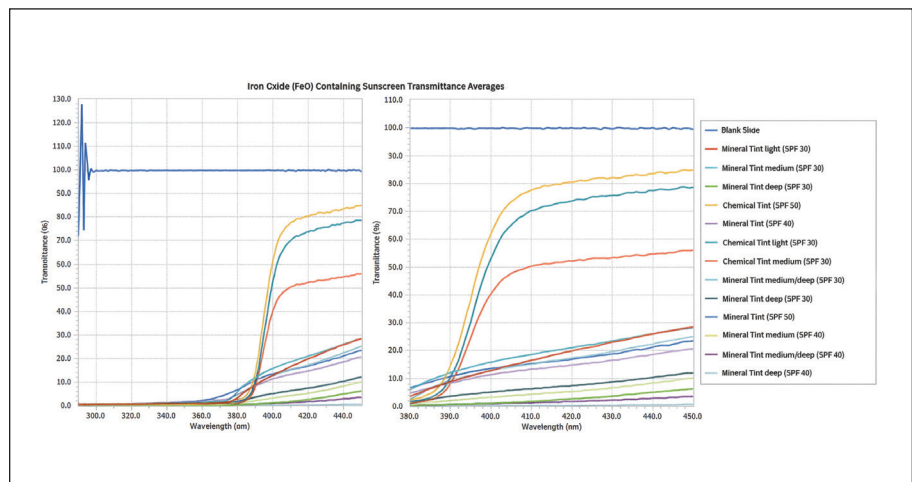
eFIGURE 1. Spectral transmittance (%) vs wavelength (nm) for mineral sunscreens from 300-450 nm (left) and with a focused spectrum from 380-450 nm (right).



eFIGURE 2. Spectral transmittance (%) vs wavelength (nm) for chemical sunscreens from 300-450 nm (left) and with a focused spectrum from 380-450 nm (right).



eFIGURE 3. Spectral transmittance (%) vs wavelength (nm) for iron oxide (FeO)-containing mineral and chemical sunscreens from 300-450 nm (left) and with a focused spectrum from 380-450 nm (right).



eTABLE 1. Characteristics of Study Sunscreen Products

| Category | Mean filter concentrations (range), % | Contains FeO? | Mean no. of antioxidants in ingredient list (range) | Mean SPF (range) | Mean NV-UVA transmittance (380-400 nm) (range), % ^a | Mean BL transmittance (450 nm) (range), % ^a |
|--------------------------------------|--|---------------|---|------------------|--|--|
| Mineral nontinted (n=4) | ZnO, 8.4 (5.0-14.4); TiO ₂ , 7.7 (6.0-9.0) | No | 1.3 (1-2) | 55 (50-70) | 19.7 (9.6-28.5) | 39.8 (23.0-47.6) |
| Chemical nontinted (n=5) | Avobenzone, 2.9 (2.5-3.0); homosalate, 8.5 (6.0-10.0); octisalate, 4.9 (4.5-5.0); octocrylene, 8.0 (7.0-10.0) | No | 1.8 (0-4) | 42 (30-60) | 29.0 (15.5-46.6) | 83.2 (61.1-97.5) |
| Mineral and chemical nontinted (n=1) | Homosalate, 10.0; octinoxate, 5.0; octocrylene, 2.0; ZnO, 8.0 | No | 0 | 30 | 55.0 | 67.2 |
| Mineral tint (n=2) | ZnO, 3.9 (0-7.8); TiO ₂ , 10.6 (10.1-11.0) | Yes | 1.5 (1-2) | 45 (40-50) | 9.3 (7.8-10.7) | 21.8 (19.9-23.7) |
| Chemical tint (n=1) | Avobenzone, 3.0; homosalate, 10.0; octisalate, 5.0; octocrylene, 10.0 | Yes | 4 | 50 | 21.90 | 85.1 |
| Mineral tint light (n=1) | ZnO, 10.0; TiO ₂ , 5.5 | Yes | 2 | 30 | 8.5 | 29.5 |
| Mineral tint medium (n=2) | ZnO, 9.0 (8.0-10.0); TiO ₂ , 11.3 (5.5-17.0) | Yes | 2 (2-2) | 35 (30-40) | 6.8 (2.0-11.5) | 19.2 (9.7-28.6) |
| Mineral tint medium/deep (n=2) | ZnO, 14.8 (8.0-21.6); TiO ₂ , 10.1 (3.2-17.0) | Yes | 1.5 (1-2) | 35 (30-40) | 4.8 (0.6-8.9) | 14.6 (3.8-25.4) |
| Mineral tint deep (n=3) | ZnO, 13.2 (8.0-21.6); TiO ₂ , 8.6 (3.2-17.0) | Yes | 1.7 (1-2) | 33.3 (30-40) | 1.3 (0.1-3.4) | 5.9 (0.3-11.9) |
| Chemical tint light (n=1) | Avobenzone, 3.0; homosalate, 9.0; octisalate, 5.0; octocrylene, 7.0 | Yes | 0 | 30 | 18.1 | 78.7 |
| Chemical tint deep (n=1) | Avobenzone, 3.0; homosalate, 9.0; octisalate, 5.0; octocrylene, 7.0 | Yes | 0 | 30 | 12.5 | 53.9 |

Abbreviations: BL, blue light; FeO, iron oxide; NV-UVA, near-visible UVA; SPF, sun protection factor; TiO₂, titanium dioxide; ZnO, zinc oxide.

^aTransmittance values represent the percentage of light transmitted in the specified range measured from spectrophotometer readings.

eTABLE 2. NV-UVA and Peak Blue Light Transmittance Between FeO-Containing Mineral (n=10) and Chemical (n=3) Filtered Sunscreens

| Variable | Filter type | Median (IQR), % | P value |
|-----------------------------------|-------------|---------------------|---------|
| NV-UVA transmittance (380-400 nm) | Mineral | 5.58 (0.59-9.35) | .007 |
| | Chemical | 18.10 (12.47-21.90) | |
| Blue light transmittance (450 nm) | Mineral | 15.90 (5.00-26.20) | .007 |
| | Chemical | 78.70 (53.90-85.10) | |

Abbreviations: FeO, iron oxide; IQR, interquartile range; NV-UVA, near-visible UVA.