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RESEARCH ARTICLE

Sunlight exposure might account for the relatively low COVID-19 morbidity and mortality in tropical countries

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ABSTRACT

The present study aimed at exploring whether sunlight exposure might account for the relative difference in COVID-19-related morbidity and mortality between tropical and non-tropical countries. A retrospective observational study was designed and data from the World Health Organization weekly COVID-19 epidemiological update was compiled. We examined the total number of confirmed COVID-19 cases per 100 000 population, as well as the total number of COVID-19-related mortalities per 100 000 population. Solar variables data were obtained from the Global Solar Atlas website (https://globalsolaratlas.info/). These data were analyzed to determine the association of sunlight exposure to COVID-19-related morbidity and mortality in tropical and non-tropical countries. Results revealed a statistically significant decrease in the number of confirmed COVID-19 cases per 100 000 population (P<0.001), as well as the number of COVID-19-related mortalities per 100 000 population (P<0.001) between tropical and non-tropical countries. Analyses of sunlight exposure data found that specific photovoltaic power output, global horizontal irradiation, diffuse horizontal irradiation and global tilted irradiation at optimum angle were significantly inversely correlated to COVID-19-related morbidity and mortality. This suggests that stronger sunlight exposure potentially leads to lower COVID-19-related morbidity and mortality. Findings from this study suggest that the relatively low COVID-19-related morbidity and mortality in tropical countries were possibly due to better sunlight exposure that translates into adequate vitamin D status.

Keywords: COVID-19; infectious disease; sunlight; tropical; vitamin D.

INTRODUCTION

The coronavirus disease 2019 (COVID-19) has caused the deadliest global pandemic since the emergence of HIV/AIDS over 40 years ago (Worobey *et al.*, 2008; Barin, 2022), and the deadliest respiratory pandemic in a century, accounting for 6 927 378 deaths to-date (as of 15th May 2023) (Ruiz-Beltrán *et al.*, 1990). This has profoundly impacted the health of humanity, the economy and the social well-being of people globally. There have been unprecedented, concerted efforts by scientists all over the globe to tackle the emergence of COVID-19, and an impressive number of studies have been undertaken to unravel the impact of the pandemic. The development of effective vaccines against SARS-CoV-2 represents a significant advancement in the global fight against COVID-19. However, despite this progress, a definitive therapeutic intervention for COVID-19 has yet to be identified and remains an active area of investigation (Yousefifard *et al.*, 2020; Gyselinck *et al.*, 2021).

Countries located on the equator and in tropical zones, in general; have lower COVID-19 associated cases and mortality as compared to sub-tropical and non-tropical countries (Carta *et al.*, 2020; Yudistira *et al.*, 2020; Aabed & Lashin, 2021; Amariles *et al.*, 2021). Based on a study in both tropical and non-tropical countries, it was suggested that warmer areas have relatively lower SARS-CoV-2 transmission and disease severity (Njenga *et al.*, 2020; Shao *et al.*, 2021). In the Southeast Asia, a study from Indonesia has reported a significant correlation between temperature and the reduction of COVID-19 cases (Tosepu *et al.*, 2020). A separate study in Indonesia found that longer period of sunlight exposure was associated with greater recovery rates from COVID-19 (Asyary & Veruswati, 2020). This correlation was consistent with an earlier report implying that sunlight exposure cannot stop the COVID-19 infection; however, sunlight exposure may positively modulate the immune system of COVID-19 sufferers, allowing them to recover from the infection. Moreover, the spread of SARS-CoV-2 in Malaysia has been postulated to be curbed by higher ambient temperature as a result of strong sunlight exposure (Suhaimi *et al.*, 2020).

Solar irradiation was shown to have strong negative correlation with incidences of COVID-19 infection in Brazil (Rosario *et al.*, 2020). Even though the number of COVID-19 cases increased considerably in Africa, case fatality rates remained low (Ghosh *et al*., 2020) and sunlight exposure was hypothesized as one of the factors impacting the spread of COVID-19. In contrast, Europe was badly affected in the initial phase of the COVID-19 pandemic, especially in the Lombardy region in Italy where the crude mortality rate was reported to be 167.6 per 100 000 population (Villani *et al*., 2020). Spain, followed by England and Wales were most likely to have experienced the largest rise in mortality over the first wave of the pandemic, with ~100 excess deaths per 100 000 population (Kontis *et al*., 2020). A separate study justified the above findings as they found that mortality rates among people afflicted with COVID-19 to be much lower in East Asian countries (0.3–5.0 deaths/million people), compared to Central European countries (391–548 deaths/million people) (Yamamoto & Bauer, 2020).

Carleton *et al*. (2021) suggested that ultraviolet (UV) exposure reduces the cumulative daily growth rate of COVID-19 cases over the subsequent 2.5 week. It is a known fact that vitamin D is obtained from type B UV exposure from sunlight (Ribeiro *et al*., 2020) and adequate sunlight exposure contributes to good vitamin D levels in humans (Okonji *et al*., 2021). The emerging evidence in the literature also suggests vitamin D's importance as a determinant for COVID-19 morbidity and mortality (Benskin, 2020; Santaolalla *et al*., 2020; Siddiqui *et al*., 2020; Xiao *et al*., 2021). This may shed light on the role of sunlight exposure in the incidence and severity of COVID-19 (Meltzer *et al*., 2020). There were suggestions that the severity and mortality from COVID-19 were much moderate in the tropical region relative to other regions of the world (Lone & Ahmad., 2020). This was due to the observation that some of the worst hit countries by the COVID-19 pandemic, such as Italy and Spain, have populations with very high vitamin D deficiency rates and are located at temperate latitudes (Calder *et al*., 2020; Ebadi & Montano-Loza, 2020; Laird *et al*., 2020).

Still, it remains uncertain whether better sunlight exposure in tropical countries accounts for the relatively low morbidity and mortality due to COVID-19 compared to countries in other geographical locations. Thus, the present study aimed at analyzing the correlation between sunlight exposure and COVID-19-related morbidity and mortality in tropical and non-tropical countries of the world.

MATERIALS AND METHODS

Tropical regions of the world are named as such because of their relatively outstanding feature of having more direct sunlight than the rest of the world. Hence, the list of tropical (n = 96) and non-tropical (n = 125) countries were listed in Supplementary Tables 1 and 2. The World Health Organization weekly COVID-19 epidemiological update (https://covid19.who.int/data) was accessed, from which data for the total number of confirmed cases per 100 000 population and the total number of mortalities per 100 000 population (data as of 1 January 2023) were retrospectively extracted for each country in the list of tropical and non-tropical countries (Supplementary Tables 1 and 2).

Sunlight exposure was represented by various solar index obtained from the Global Solar Atlas website. The solar index variables; (i) specific photovoltaic power output (PVOUT specific); (ii) direct normal irradiation (DNI); (iii) global horizontal irradiation (GHI); (iv) diffuse horizontal irradiation (DIF); and (v) global tilted irradiation at optimum angle (GTI opto) were extracted from https://globalsolaratlas.info/support/user-guide based on the values recorded in the capital cities of each country. Several countries (i.e. Democratic Republic of Congo, Singapore, Faroe Islands, Finland and Iceland) have been excluded from this study due to the unavailability of data from the website.

The normality of the data for the number of cases per 100 000 population and the number of deaths per 100 000 population were examined using the Shapiro-Wilk test (Shaphiro & Wilk, 1965). The Shapiro-Wilk test found the data to be non-normally distributed, therefore the Mann-Whitney U test was employed as a non-parametric test to compare differences between the number of cases per 100 000 population and the number of deaths per 100 000 population (Mann & Whitney, 1947). Spearman rank correlation test was performed to test the hypothesis on whether the solar index variables were associated to COVID-19 confirmed cases and mortality. Data collected were analyzed using the SPSS program for Windows, version 20.0 (SPSS Inc, Chicago, IL). A heatmap was generated using Seaborn (v0.12.2) to visualize the correlation coefficients between COVID-19-related cases and mortality with various solar index variables (Waskom, 2021).

RESULTS

Since the data collected was non-parametric (Table 1), the Mann-Whitney U test (Table 2) was performed to compare differences between the number of COVID-19 cases per 100 000 population and the number of COVID-19 deaths per 100 000 population, respectively.

In Table 2, statistical analyses were performed between tropical and non-tropical countries based on the accumulated COVID-19-related morbidity and mortality data, with the total number of 96 tropical and 125 non-tropical countries, respectively. The tropical

Table 1. Analysis of the normality of the number of cases per 100 000 population and the number of deaths per 100 000 population

Variable	Statistic	df	Significance, *P*
Total confirmed cases per 100 000 population	0.870	221	<0.001
Total mortality per 100 000 population	0.871	221	<0.001

Table 2. Statistical analyses of the variables between tropical and non-tropical countries based on COVID-19-related morbidity and mortality

Variable	Country	N	Median (IQR)	Mann-Whitney U test	Significance, *P*
Total confirmed cases per 100 000 population	Tropical	96	3469 (449.15-16567.80)	3085	<0.001
	Non- tropical	125	22572.90 (7995.65-43713.40)		
Total mortality per 100 000 population	Tropical	96	39.45 (7.60-157.28)	3877	<0.001
	Non- tropical	125	131.60 (46.60-243.80)		

Table 3. Solar index variables of tropical and non-tropical countries

Country	Data	Specific photovoltaic power output, PVOUT specific (kWh/kWp)	Direct normal irradiation, DNI (kWh/m^2)	Global horizontal irradiation, GHI (kWh/m^2)	Diffuse horizontal irradiation, DIF (kWh/m^2)	Global tilted irradiation at optimum angle, GTI opto (kWh/m^2)
Tropical	Min.	1077	631	1322	632	1345
	Median	1642	1628	1991	847	2069
	IQR	1506–1730	1267–1885	1850–2108	777–939	1894–2178
	Max.	1973	2488	2322	1063	2453
Non-tropical	Min.	957	762	160	473	1121
	Median	1532	1609	1688	626	1908
	IQR	1260–1709	1164–1886	1296–2018	574–734	1519–2134
	Max.	1982	2860	2346	1031	2551

countries group was associated with COVID-19 by median values of 3469 (Interquartile range (IQR): 449.15-16567.80) for the total number of confirmed cases per 100 000 population, and 39.45 (IQR: 7.60-157.28) for the total mortality per 100 000 population. By comparison, the non-tropical countries group was numerically having higher median values of 22572.90 (IQR: 7995.65-43713.40) for the total number of confirmed cases per 100 000 population, and 131.60 (IQR: 46.60-243.80) for the total mortality per 100 000 population, respectively. The Mann Whitney-U test revealed a statistically significant increase in the total number of confirmed cases per 100 000 population ($P<0.001$) and total mortality per 100 000 population ($P<0.001$) for non-tropical countries in comparison to tropical countries, respectively (Table 2). This suggests that tropical countries have lower burden of COVID-19 compared to non-tropical countries.

Solar index variables data showed that the tropical countries have higher values of the minimum PVOUT specific, GHI, DIF and GTI opto, as compared to the non-tropical countries (Table 3). However, the minimum value for DNI is higher in non-tropical countries (Table 3). Non-tropical countries also recorded higher maximum values of PVOUT specific, DNI, GHI and GTI opto (Table 3). The overall solar index variables data indicated that there are differences in solar irradiation between tropical and non-tropical countries. Based on the Spearman rank correlation test, the average of PVOUT specific, DNI, GHI, DIF and GTI opto were correlated with COVID-19 confirmed cases per 100 000 population by -0.261, -0.074, -0.367, -0.539 and -0.305, respectively (Figure 1). A similar pattern was found with COVID-19 mortality per 100 000 population with the average of PVOUT specific, DNI, GHI, DIF and GTI opto correlation coefficient values of -0.195, 0.006, -0.306, -0.506 and -0.233, respectively (Figure 1). The analyses indicated that PVOUT specific, GHI, DIF and GTI opto were inversely correlated with the COVID-19 confirmed cases and mortality, and these correlations were statistically significant. As for DNI, it was inversely correlated with COVID-19 confirmed cases but directly correlated with COVID-19 mortality; however these correlations were not statistically significant.

The heatmap in Figure 1 also illustrates the correlation coefficients between different solar index variables (PVOUT, DNI, GHI, DIF, and GTI opto) and the number of COVID-19 confirmed cases per 100 000 population, as well as between solar index variables and the number of COVID-19 mortality per 100 000 population. The heatmap analysis indicated that the correlation of COVID-19 cases and mortality with solar index variables were generally negative, with the exception of DNI (Figure 1). The darker the gradient of the blue color, the more intense the negative correlations (Figure 1). The annotations within each cell indicated the correlation coefficient values. The heatmap

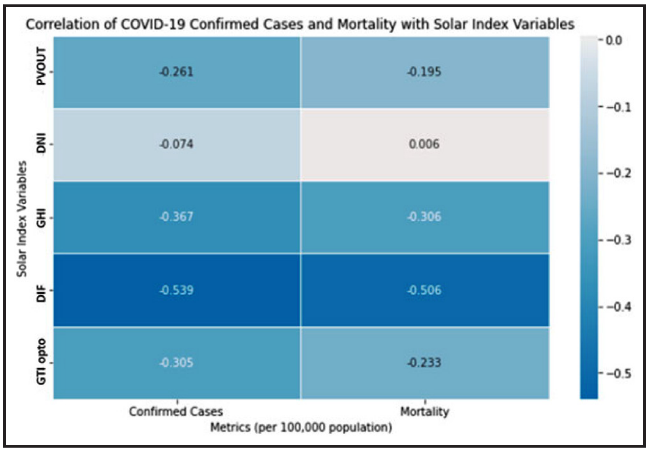

Figure 1. Heatmap analysis of the correlation coefficients between COVID-19 confirmed cases and mortality with solar index variables. The *P* values for the correlation coefficients for specific photovoltaic power output, PVOUT (confirmed cases, $P<0.001$; mortality, $P=0.004$), direct normal irradiation, DNI (confirmed cases, $P=0.2821$; mortality, $P=0.928$), global horizontal irradiation, GHI (confirmed cases, $P<0.001$; mortality, $P<0.001$), diffuse horizontal irradiation, DIF (confirmed cases, $P<0.001$; mortality, $P<0.001$), global tilted irradiation at optimum angle, GTI (confirmed cases, $P<0.001$; mortality, $P<0.001$).

analysis showed that as the values of the solar index variables increased, the number of COVID-19 cases and mortality declined. Specifically, we observed that DIF has the strongest negative correlation with both COVID-19 cases and mortality, followed by GHI, GTI opto and PVOUT. DNI has a weak positive correlation with COVID-19-related mortality (Figure 1).

DISCUSSION

This study investigated whether the relative difference in morbidity and mortality due to COVID-19 between tropical and non-tropical countries could be a result of sunlight exposure. The main finding from this study suggested that there is a statistically significant decrease in the number of confirmed cases of COVID-19 per 100 000 population as well as in the number of mortality due to COVID-19 per 100 000 population, in tropical countries as compared to non-tropical countries. This is particularly interesting because we took into account the variations in population size and demographics across countries by considering the number of confirmed COVID-19 cases and fatalities per 100 000 population. This approach was used to ensure that the sample size or population structure across the countries under investigation did not influence the results. This finding further corroborated results from a plethora of previous studies that found that the mortality and morbidity as a result of COVID-19 varied between tropical and non-tropical countries, with tropical countries reported to have relatively lower COVID-19 morbidity and mortality (Carta *et al*., 2020; Njenga *et al*., 2020; Yudistira *et al*., 2020; Aabed & Lashin, 2021; Amariles *et al*., 2021; Shao *et al*., 2021). In addition, sunlight exposure represented by solar index variables provided by the Global Solar Atlas website was found to be inversely correlated to the COVID-19 confirmed cases and mortality in tropical and non-tropical countries, implying that the more intense the sunlight exposure, the lower the COVID-19-related morbidity and mortality.

Lansiaux *et al*. (2020) and Naudet *et al*. (2020) first reported a correlation between the average annual sunlight hours and COVID-19 mortality rate, suggesting the potential protective effect of sunlight exposure against COVID-19 mortality among the residents of metropolitan continental of France. Despite facing heavy criticisms for shortcomings, including major statistical flaws that might have undermined the credibility of its findings, the studies still prompted a discourse regarding the correlation between sunlight exposure and COVID-19. A study by Panarese & Shahini (2020) that analyzed the worldwide mortality caused by the COVID-19 pandemic according to geographical distribution in 108 countries found that COVID-19 mortality and hospitalization rates were higher in the northern latitude countries compared to those closer to the equator. These findings suggest the possible relationship between sunlight exposure and COVID-19 as countries in the northern latitude have relatively low UV exposure, hence possibly lower vitamin D levels (Baktash *et al*., 2021).

The potential role of vitamin D in COVID-19 has received a lot of attention since 2020 (Bilezikian *et al*., 2020; Cutolo *et al*., 2020; Martineau & Forouhi, 2020; Zemb *et al*., 2020) partly due to its immunomodulatory function through innate/adaptive immunity and its inflammatory-modulation function that mitigate cytokine storm (Muhammad *et al*., 2022). At least 14 observational studies involving different locations and populations around the world have reported that serum vitamin D (25-hydroxyvitamin D) concentrations were inversely correlated to COVID-19 severe morbidity (Mercola *et al*., 2020). While the precise mechanism of association between vitamin D levels and COVID-19 severity and mortality needs further investigation, several biological roles of vitamin D have been established such as the immunomodulatory effects on both innate and adaptive immunity (Mohan *et al*., 2020), modulatory effects on inflammatory cytokine production (Weir *et al*., 2020), increased expression of angiotensin-converting enzyme 2 concentrations (Bergman, 2021) and maintaining endothelial integrity (Mercola *et al*., 2020).

Sulli *et al*. (2021) undertook a comparative study on 65 COVID-19 patients and 65 sex- and age-matched control subjects to correlate their serum level of 25-hydroxyvitamin D with clinical parameters of lung functional status. The study revealed that vitamin D deficiency is associated with more severe lung involvement, longer disease duration, and risk of death due to COVID-19 in elders. Radujkovic *et al*. (2020) further demonstrated an association between death due to COVID-19 in a cohort of 185 COVID-19 patients with vitamin D deficiency or insufficiency. A study also reported the insufficiency and deficiency of vitamin D in COVID-19 patients (Pinzon *et al*., 2020). Studies by Brenner and Schöttker (2020) stressed a compelling emerging number of evidence on vitamin D deficiency and outcome of COVID-19, imploring the potential of vitamin D supplementation as countermeasures for prevention and reducing the severity of COVID-19.

The findings of this study were consistent with previous research that demonstrated a potential link between sunlight exposure, vitamin D status, and COVID-19 outcomes (McCartney & Byrne, 2020; Meltzer *et al*., 2020; Gibbons *et al*., 2022). The inverse correlation between sunlight exposure and COVID-19 outcomes observed in this study suggests that sunlight exposure may play a protective role against the virus (D'Avolio *et al*., 2020; Rhodes *et al*., 2020). However, it is important to note that this study has several limitations. Firstly, this study was a data-based observational study, so causality cannot be established. Secondly, the study did not consider demographical factors that may contribute to the observed differences in COVID-19 outcomes between tropical and non-tropical countries, such as population density, age distribution, and healthcare system capacity. Finally, the present study did not account for the impact of miscellaneous factors, such as vitamin D supplementation and daily exposure of sunlight, on COVID-19 outcomes.

While the present study provided further support to the potential important role of vitamin D sufficiency in mitigating COVID-19, more definitive studies involving actual measurement of vitamin D level in the population and actual exposure to sunlight still need to be done. Further research is required to confirm these findings and to elucidate the underlying mechanisms by which sunlight exposure may influence COVID-19 outcomes.

CONCLUSIONS

The present study found significant decrease in the total number of COVID-19 confirmed cases per 100 000 population and the mortality per 100 000 population in tropical countries in comparison to non-tropical countries, respectively. Sunlight exposure, represented by various solar index variables were significantly inversely correlated to COVID-19-related morbidity and mortality, suggesting that sunlight exposure may account for the relatively low COVID-19-related morbidity and mortality in tropical countries. This finding carries significant implications, as it is well-established that UV irradiation resulting from sunlight exposure is a crucial determinant of the important regulator of the immune system; vitamin D.

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Conflict of interest statement

The authors declare that there are no conflicts of interest.

REFERENCES

Aabed, K. & Lashin, M.M.A. (2021). An analytical study of the factors that influence COVID-19 spread. *Saudi Journal of Biological Sciences* **28**: 1177-1195. https://doi.org/10.1016/j.sjbs.2020.11.067

Amariles, P., Granados, J., Ceballos, M. & Montoya, C.J. (2021). COVID-19 in Colombia endpoints. Are we different, like Europe? *Research in Social and Administrative Pharmacy* **17**: 2036-2039. https://doi.org/10.1016/j.sapharm.2020.03.013

Asyary, A. & Veruswati, M. (2020). Sunlight exposure increased COVID-19 recovery rates: a study in the central pandemic area of Indonesia. *Science of The Total Environment* **729**: 139016. https://doi.org/10.1016/j.scitotenv.2020.139016

Baktash, V., Hosack, T., Zahari, N., Shah, S., Kandiah, P., Van den Abbeele, K., Mandal, A.K.J. & Missouris, C.G. (2021). Vitamin D status and outcomes for hospitalised older patients with COVID-19. *Postgraduate Medical Journal* **97**: 442-447. https://doi.org/10.1136/postgradmedj-2020-138712

Barin, F. (2022). HIV / AIDs as a model for emerging infectious disease: origin, dating and circumstances of an emblematic epidemiological success. *La Presse Mᶦdicale* **51**: 104128. https://doi.org/10.1016/j.lpm.2022.104128

Benskin, L.L. (2020). A basic review of the preliminary evidence that COVID-19 risk and severity is increased in Vitamin D deficiency. *Frontiers in Public Health* **8**: 513. https://doi.org/10.3389/fpubh.2020.00513

Bergman, P.J. (2021). The link between Vitamin D and COVID 19: distinguishing facts from fiction. *Journal of Internal Medicine* **289**: 131-133. https://doi.org/10.1111/joim.13158

Bilezikian, J.P., Bikle, D., Hewison, M., Lazaretti-Castro, M., Formenti, A.M., Gupta, A., Madhavan, M.V., Nair, N., Babalyan, V., Hutchings, N. *et al*. (2020). Mechanisms in endocrinology: vitamin D and COVID-19. *European Journal of Endocrinology* **183**: R133-R147. https://doi.org/10.1530/EJE-20-0665

Brenner, H. & Schöttker, B.J.N. (2020). Vitamin D insufficiency may account for almost nine of ten COVID-19 deaths: time to act. Comment on: "Vitamin D deficiency and outcome of COVID-19 patients". Nutrients 2020, 12, 2757. *Nutrients* **12**: 3642. https://doi.org/10.3390/nu12123642

Calder, P.C., Carr, A.C., Gombart, A.F. & Eggersdorfer, M.J.N. (2020). Optimal nutritional status for a well-functioning immune system ss an important factor to protect against viral infections. *Nutrients* **12**: 1181. https://doi.org/10.3390/nu12041181

Carleton, T., Cornetet, J., Huybers, P., Meng, K.C. & Proctor, J. (2021). Global evidence for ultraviolet radiation decreasing COVID-19 growth rates. *Proceedings of the National Academy of Sciences* **118**: e2012370118. https://doi.org/10.1073/pnas.2012370118

Carta, M.G., Scano, A., Lindert, J., Bonanno, S., Rinaldi, L., Fais, S. & Orrú, G. (2020). Association between the spread of COVID-19 and weather-climatic parameters. *European Review for Medical and Pharmacological Sciences* **24**: 8226-8231. https://doi.org/10.26355/eurrev_202008_22512

Cutolo, M., Paolino, S. & Smith, V. (2020). Evidences for a protective role of vitamin D in COVID-19. *RMD Open* **6**: e001454. http://doi.org/10.1136/rmdopen-2020-001454

D'Avolio, A., Avataneo, V., Manca, A., Cusato, J., De Nicolò, A., Lucchini, R., Keller, F. & Cantù, M. (2020). 25-Hydroxyvitamin D concentrations are lower in patients with positive PCR for SARS-CoV-2. *Nutrients* **12**: 1359. https://doi.org/10.3390/nu12051359

Ebadi, M. & Montano-Loza, A.J. (2020). Perspective: improving vitamin D status in the management of COVID-19. *European Journal of Clinical Nutrition* **74**: 856-859. https://doi.org/10.1038/s41430-020-0661-0

Ghosh, D., Bernstein, J.A. & Mersha, T.B. (2020). COVID-19 pandemic: the African paradox. *Journal of Global Health* **10**: 020348. https://doi.org/10.7189/jogh.10.020348

Gibbons, J.B., Norton, E.C., McCullough, J.S., Meltzer, D.O., Lavigne, J., Fiedler, V.C. & Gibbons, R.D. (2022). Association between vitamin D supplementation and COVID-19 infection and mortality. *Scientific Reports* **12**: 19397. https://doi.org/10.1038/s41598-022-24053-4

Gyselinck, I., Liesenborghs, L., Landeloos, E., Belmans, A., Verbeke, G., Verhamme, P., Vos, R., Janssens, W. & DAWn-Azithro consortium. (2021). Direct antivirals working against the novel coronavirus: azithromycin (Dawn-Azithro), a randomized, multicenter, open-label, adaptive, proof-of-concept clinical trial of new antivirals working against SARS-CoV-2–zzithromycin trial. *Trials* **22**: 126. https://doi.org/10.1186/s13063-021-05033-x

Kontis, V., Bennett, J.E., Rashid, T., Parks, R.M., Pearson-Stuttard, J., Guillot, M., Asaria, P., Zhou, B., Battaglini, M., Corsetti, G. *et al*. (2020). Magnitude, demographics and dynamics of the effect of the first wave of the COVID-19 pandemic on all-cause mortality in 21 industrialized countries. *Nature Medicine* **26**: 1919-1928. https://doi.org/10.1038/s41591-020-1112-0

Laird, E., Rhodes, J. & Kenny, R.A. (2020). Vitamin D and inflammation: potential implications for severity of COVID-19. *Irish Medical Journal* **113**: 81.

Lansiaux, È., Pébaÿ, P.P., Picard, J.-L. & Forget, J. (2020). COVID-19 and vit-D: disease mortality negatively correlates with sunlight exposure. *Spatial and Spatio-temporal Epidemiology* **35**: 100362. https://doi.org/10.1016/j.sste.2020.100362

Lone, S.A. & Ahmad, A. (2020). COVID-19 pandemic – an African perspective. *Emerging Microbes and Infection* **9**: 1300-1308. https://doi.org/10.1080/22221751.2020.1775132

Mann, H.B. & Whitney, D.R. (1947). On a test of whether one of two random variables is stochastically larger than the other. *The Annals of Mathematical Statistics* **18**: 50-60. https://doi.org/10.1214/aoms/1177730491

Martineau, A.R. & Forouhi, N.G. (2020). Vitamin D for COVID-19: a case to answer? *Lancet Diabetes and Endocrinology* **8**: 735-736. https://doi.org/10.1016/S2213-8587(20)30268-0

McCartney, D.M. & Byrne, D.G. (2020). Optimisation of Vitamin D status for enhanced immuno-protection against COVID-19. *Irish Medical Journal* **113**: 58.

Meltzer, D.O., Best, T.J., Zhang, H., Vokes, T., Arora, V. & Solway, J. (2020). Association of vitamin D status and other clinical characteristics with COVID-19 test results. *JAMA Network Open* **3**: e2019722. https://doi.org/10.1001/jamanetworkopen.2020.19722

Mercola, J., Grant, W.B. & Wagner, C.L. (2020). Evidence regarding vitamin D and risk of COVID-19 and its severity. *Nutrients* **12**: 3361. https://doi.org/10.3390/nu12113361

Mohan, M., Cherian, J.J. & Sharma, A. (2020). Exploring links between vitamin D deficiency and COVID-19. *PLoS Pathogens* **16**: e1008874. https://doi.org/10.1371/journal.ppat.1008874

Muhammad, M., Hassan, T.M., Baba, S.S., Radda, M.I., Mutawakkil, M.M., Musa, M.A., AbuBakar, S., Loong, S.K. & Yusuf, I. (2022). Exploring NFκB pathway as a potent strategy to mitigate COVID-19 severe morbidity and mortality. *Journal of Public Health in Africa* **13**(3): 1679. https:// doi.org/10.4081/jphia.2022.1679

Naudet, F., Locher, C., Braillon, A. & Gillibert, A. (2020). Letter to the editor: COVID-19 and Vit-D: disease mortality negatively correlates with sunlight exposure. *Spatial and Spatio-temporal Epidemiology* **35**: 100373. https://doi.org/10.1016/j.sste.2020.100373

Njenga, M.K., Dawa, J., Nanyingi, M., Gachohi, J., Ngere, I., Letko, M., Otieno, C.F., Gunn, B.M. & Osoro, E. (2020). Why ss there low morbidity and mortality of COVID-19 in Africa? *American Journal of Tropical Medicine and Hygiene* **103**: 564-569. https://doi.org/10.4269/ajtmh.20-0474

Okonji, E.F., Okonji, O.C., Mukumbang, F.C. & Van Wyk, B. (2021). Understanding varying COVID-19 mortality rates reported in Africa compared to Europe, Americas and Asia. *Tropical Medicine and International Health* **26**: 716-719. https://doi.org/10.1111/tmi.13575

Panarese, A. & Shahini, E. (2020). COVID-19, and vitamin D. *Alimentary Pharmacology & Therapeutics* **51**: 993-995. https://doi.org/10.1111/apt.15752

Pinzon, R.T., Angela. & Pradana, A.W. (2020). Vitamin D deficiency among patients with COVID-19: case series and recent literature review. *Tropical Medicine and Health* **48**: 102. https://doi.org/10.1186/s41182-020-00277-w

Radujkovic, A., Hippchen, T., Tiwari-Heckler, S., Dreher, S., Boxberger, M. & Merle, U.J.N. (2020). Vitamin D deficiency and outcome of COVID-19 patients. *Nutrients* **12**: 2757. https://doi.org/10.3390/nu12092757

Rhodes, J.M., Subramanian, S., Laird, E. & Kenny, R.A. (2020). Editorial: low population mortality from COVID-19 in countries south of latitude 35 degrees North supports vitamin D as a factor determining severity. *Alimentary Pharmacology and Therapeutics* **51**: 1434-1437. https://doi.org/10.1111/apt.15777

Ribeiro, H., de Santana, K.V.d.S., Oliver, S.L., Rondɳ, P.H.d.C., Mendes, M.M., Charlton, K. & Lanham-New, S. (2020). Does vitamin D play a role in the management of COVID-19 in Brazil? *Revista de Saude Publica* **54**: 53. https://doi.org/10.11606/s1518-8787.2020054002545

Rosario, D.K.A., Mutz, Y.S., Bernardes, P.C. & Conte-Junior, C.A. (2020). Relationship between COVID-19 and weather: case study in a tropical country. *International Journal of Hygiene and Environmental Health* **229**: 113587. https://doi.org/10.1016/j.ijheh.2020.113587

Ruiz-Beltrán, R., Herrero-Herrero, J.I., Martín-Sánchez, A.M. & Martín-Gonzalez, J.A. (1990). Prevalence of antibodies to *Rickettsia conorii*, *Coxiella burnetii* and *Rickettsia typhi* in Salamanca province (Spain). Serosurvey in the human population. *European Journal of Epidemiology* **6**: 293-299. https://doi.org/10.1007/BF00150435

Santaolalla, A., Beckmann, K., Kibaru, J., Josephs, D., Van Hemelrijck, M. & Irshad, S. (2020). Association between vitamin D and novel SARS-CoV-2 respiratory dysfunction – a scoping review of current evidence and its implication for COVID-19 pandemic. *Frontiers Physiology* **11**: 564387. https://doi.org/10.3389/fphys.2020.564387

Shao, W., Xie, J. & Zhu, Y. (2021). Mediation by human mobility of the association between temperature and COVID-19 transmission rate. *Environmental Research* **194**: 110608. https://doi.org/10.1016/j.envres.2020.110608

Shaphiro, S.S. & Wilk, M.B. (1965). An analysis of variance test for normality. *Biometrika* **52**: 591-611. https://doi.org/10.2307/2333709

Siddiqui, M., Manansala, J.S., Abdulrahman, H.A., Nasrallah, G.K., Smatti, M.K., Younes, N., Althani, A.A. & Yassine, H.M. (2020). Immune modulatory effects of vitamin D on viral infections. *Nutrients* **12**: 2879. https://doi.org/10.3390/nu12092879

Suhaimi, N.F., Jalaludin, J. & Latif, M.T. (2020). Demystifying a possible relationship between COVID-19, air quality and meteorological factors: evidence from Kuala Lumpur, Malaysia. *Aerosol and Air Quality Research* **20**: 1520-1529. https://doi.org/10.4209/aaqr.2020.05.0218

Sulli, A., Gotelli, E., Casabella, A., Paolino, S., Pizzorni, C., Alessandri, E., Grosso, M., Ferone, D., Smith, V. & Cutolo, M.J.N. (2021). Vitamin D and lung outcomes in elderly COVID-19 patients. *Nutrients* **13**: 717. https://doi.org/10.3390/nu13030717

Tosepu, R., Gunawan, J., Effendy, D.S., Ahmad, L.O.A.I., Lestari, H., Bahar, H. & Asfian, P. (2020). Correlation between weather and COVID-19 pandemic in Jakarta, Indonesia. *Science of The Total Environment* **725**: 138436. https://doi.org/10.1016/j.scitotenv.2020.138436

Villani, L., McKee, M., Cascini, F., Ricciardi, W. & Boccia, S. (2020). Comparison of deaths rates for COVID-19 across Europe during the first wave of the COVID-19 pandemic. *Frontiers in Public Health* **8**: 620416. https://doi.org/10.3389/fpubh.2020.620416

Waskom, M.L.J. (2021). Seaborn: statistical data visualization. *The Journal of Open Source Software* **6**: 3021. https://doi.org/10.21105/joss.03021

Weir, E.K., Thenappan, T., Bhargava, M. & Chen, Y.J. (2020). Does vitamin D deficiency increase the severity of COVID-19? *Clinical Medicine* **20**: e107-e108. https://doi.org/10.7861/clinmed.2020-0301

Worobey, M., Gemmel, M., Teuwen, D.E., Haselkorn, T., Kunstman, K., Bunce, M., Muyembe, J.J, Kabongo, J.M.M., Kalengayi, R.M., Van Marck, E. *et al*. (2008). Direct evidence of extensive diversity of HIV-1 in Kinshasa by 1960. *Nature* **455**: 661-664. https://doi.org/10.1038/nature07390

Xiao, D., Li, X., Su, X., Mu, D. & Qu, Y. (2021). Could SARS-CoV-2-induced lung injury be attenuated by vitamin D? *International Journal of Infectious Diseases* **102**: 196-202. https://doi.org/10.1016/j.ijid.2020.10.059

Yamamoto, N. & Bauer, G. (2020). Apparent difference in fatalities between Central Europe and East Asia due to SARS-CoV-2 and COVID-19: four hypotheses for possible explanation. *Medical Hypotheses* **144**: 110160. https://doi.org/10.1016/j.mehy.2020.110160

Yousefifard, M., Zali, A., Ali, K.M., Neishaboori, A.M., Zarghi, A., Hosseini, M. & Safari, S. (2020). Antiviral therapy in management of COVID-19: a systematic review on current evidence. *Archives of Academic Emergency Medicine* **8**: e45.

Yudistira, N., Sumitro, S.B., Nahas, A. & Riama, N.F. (2020). UV light influences COVID-19 activity through big data: trade offs between northern subtropical, tropical, and southern subtropical countries. *MedRxiv* **[Preprint]**. https://doi.org/10.1101/2020.04.30.20086983

Zemb, P., Bergman, P., Camargo, C.A., Cavalier, E., Cormier, C., Courbebaisse, M., Hollis, B., Joulia, F., Minisola, S., Pilz, S. *et al*. (2020). Vitamin D deficiency and the COVID-19 pandemic. *Journal of Global Antimicrobial Resistance* **22**: 133-134. https://doi.org/10.1016/j.jgar.2020.05.006