UV-lamps for terrariums: Their spectral characteristics and efficiency in promoting vitamin D_3 synthesis by UVB irradiation

JUKKA LINDGREN
KÄÄNTÄNYT/TRANSLATED BY: TIINA SIITONEN, JUKKA LINDGREN, BARRY BROWN

Sufficient irradiation within a narrow sub-band of the UVB range is a prerequisite for the photosynthesis of vitamin D_3 in skin. Although radiation below wavelength of 300 nm (nanometres) promotes photosynthesis of vitamin D_3, radiation above 300 nm destroys vitamin D_3 that has been already synthesised in skin tissue or nutritionally obtained. Furthermore, skin temperature has a significant effect on the pace of vitamin D_3 synthesis. In terrarium, the required UVB-radiation has to be artificially produced with dedicated lamps. In the study, the characteristics of light produced by fourteen different models of UV and full spectrum lamps specifically designed for terrarium use were measured over a range of 250–800 nm. As a reference, the spectrum of natural sunlight was also measured when the sun was at its highest point of elevation in the southern sky of Finland. The proportion of radiation energy that takes part in the photosynthesis of vitamin D_3 was determined and the D_3 yield index was calculated. Significant differences as large as thousand fold were found in the D_3 yield indices. It is concluded that the percentage of UVB radiation from the total radiation figure does not necessarily give a true indication of a lamp's capability to maintain cutaneous production of vitamin D_3.

Exclusively herbivorous reptiles like lizards and tortoises cannot obtain sufficient amount of vitamin D_3 solely from their natural diet. Nevertheless, vitamin D_3 is fundamental to ensure normal functioning of many organs. In addition to regulating calcium metabolism, vitamin D_3 also acts as a hormone in organ development. Active vitamin D_3 also takes part in the functioning of immune system. Furthermore, it controls build up of bone matter and also appears to be important for female fertility. (Jones *et. al.*, 1998).

In plants, the large proportion of D-vitamins consists of vitamin D_2 (ergocalciferol) that is not absorbed very well by the intestinal system. Vitamin D_3 (cholecalciferol) promotes calcium metabolism much more efficiently, but fresh plants are almost completely devoid of it. Only sun-dried plants, like hay for instance, contain small amounts of vitamin D_3 (Raulio, J., pers. comm.). Herbivorous animals must compensate for this deficiency by photosynthesising vitamin D_3 by ultraviolet light.

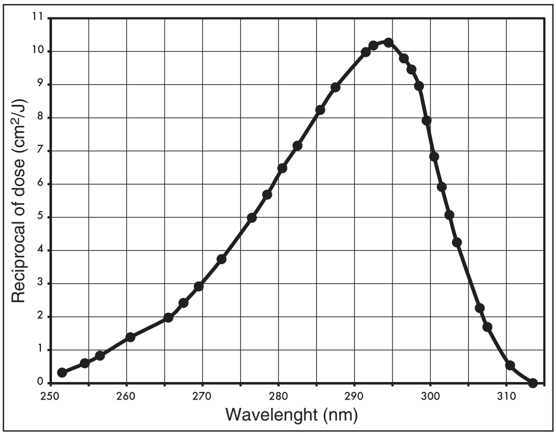

Figure 1. Action spectrum of 7-DHC to PreD_3 conversion.

Vitamin D_3 is photosynthesised in the skin of terrestrial vertebrates and birds by the action of UVB radiation on 7-dehydrocholesterol (7-DHC). This steroid is most sensitive to radiation in the range of 270–305 nm (fig. 1. MacLaughlin *et. al.*, 1982). This range coincides with the lowest wavelengths of sunlight that can actually penetrate the atmosphere, the lower limit of the active range being 290 nm. While absorbed by a 7-DHC molecule, the UVB photon opens the ring structure of the molecule and converts it to a precursor of vitamin D_3 (preD_3). Subsequently, this is thermally isomerised slowly, over several days, to cholecalciferol that is the actual vitamin D_3.

Vitamin D_3 is transferred to the liver by the vitamin D binding protein, where it is transformed to calcidiol [25-hydroxycholecalciferol, 25[OH] D_3]. Calcidiol is then transferred to the kidneys, which in association with parathyroid hormone, further convert it to calcitriol [1,25-dihydroxycholecalciferol, 1,25[OH]$_2$$D_3$]. A recent study carried out in the University of Tampere (Lou *et. al.*, 2003) suggests that both of these metabolic products have their own significant role in the operation of the organic system: calcidiol acts as a hormone and controls for instance cell division, whereas calcitriol takes part in the calcium/phosphate regulatory mechanism and is thereby the actual active substance while controlling the calcium level of blood serum. It increases absorption of calcium and phosphate through the wall of small intestine and also controls their transfer from bone matter to plasma. Calcitriol also decreases the amount of calcium and phosphate secreted in urine. Since calcitriol receptors have been found in various tissues, it apparently also has several other tasks within organs. For the sake of simplicity, calcidiol and calcitriol are by common consensus called vitamin D, even though a more accurate name for calcidiol would be hormone D.

If excess preD_3 is formed in the skin it is further photoisomerized by UVB irradiation to lumisterol and tachysterol. This rapid reaction is photo-reversible: radiation isomerises tachysterol back to preD_3, although at a slower rate, and further to lumisterol. Being the least photosensitive product, lumisterol is finally accumulated to plasma. These reactions act as a natural regulation mechanism, preventing excessive synthesis of vitamin D_3 under strong UVB irradiation.

The spectral characteristics of light in the UVB/UVA range are an important factor in vitamin D_3 photosynthesis. While 7-DHC is sensitive to irradiation up to 315 nm, cutaneous vitamin D_3 that has been photosynthesised or obtained nutritionally is destroyed by radiation up to 330 nm (Webb *et. al.*, 1989.) This makes any radiation in the range 315–330 nm highly undesirable for the synthesis of vitamin D_3.

The skin temperature also plays a very important role in the synthesis of vitamin D_3. This was established in a study with green iguana (Iguana iguana), common frog (Rana temporaria) and human skin samples (Holick *et. al.*, 1995.) In vitro tests showed that a temperature increase from 5 °C to 25 °C accelerated thermal isomerization of vitamin D_3 by eight. In a separate study with human and chicken skin at even higher temperatures (40 °C), the tendency remained the same.

To ensure that this complex chain of reactions on reptile's skin can be completed, sufficiently high irradiation at wavelengths 270–315 nm is required, while higher wavelengths (315–330 nm) should be avoided. The skin temperature must also be high enough. Low UVB irradiation below 315 nm or too low a body temperature of a cold blooded (poikilothermic) animal might create an undesirable situation where new vitamin D_3 is no longer produced in the skin and at the time the radiation starts destroying cutaneous vitamin D_3.

Under this hypothesis, non-equatorial herbivorous animals should be susceptible to vitamin D_3 deficiency. The detrimental effects of photodestruction of vitamin D_3, as described above, may however be alleviated by the equilibrium seeking properties of many biological processes (Ball, J., pers. comm.). It is possible, for instance, that the membrane enhancement of the production of vitamin D_3 (Holick *et. al.*, 1995) may automatically compensate for the reduced radiation.

It should be noted that the theory and research discussed above relate to human skin. However, the chemistry of the skin of terrestrial vertebrates is similar enough to that of human to justify the theory to be extrapolated to reptiles as well. Human osteoporosis caused by UVB deficiency is well documented in Nordic countries, but this is yet to be demonstrated in wild reptiles.

In conclusion, to ensure sufficient vitamin D_3 synthesis, a terrarium must be fitted with efficient artificial lighting with broad-spectrum UVB lamps and temperature must be kept sufficiently high in the basking area. More specifically, the radiation in the region of short wavelengths must reach far enough.

Over recent years, there have been numerous research papers written on the quality of lamps designed for terrarium use. Some studies have included only a few lamps, while some studies cover lamps of which many are no longer available (e.g. Ball, 1995). This makes evaluation of lamps difficult, as there are no comparable results available for current models. For this study, as large as possible selection of lamps available in Finland was obtained. Some lamps that are not locally commonly available were also included, either because they were especially interesting or had received contradictory reviews elsewhere.

Several papers have focused only on the percentage of UVB radiation. As cutaneous vitamin D_3 synthesis is only sustained in an extremely narrow band within the crossover of UVB and UVC, the full UVB-range irradiance figure alone does not tell the whole truth about the ability of a lamp to promote vitamin D_3 production. More detailed information is required.

For the purpose of this study, the D_3 Yield Index was developed to indicate the amount of radiation that can actually participate in the photosynthesis of vitamin D_3. A plain index number such as the Yield Index used here shows this in an unambiguous manner. The calculation method for the index was devised in such a way that it can be easily adapted to any reference. Within the framework of this study, the index value is based on radiation energy of the sun in midsummer noon in Finland. Measuring the sunlight with compatible equipment at the equator would enable the index to be adjusted for use as a universal baseline.

The results indicate significant variation in the capability of different lamps to promote the photosynthesis of vitamin D_3. They range from half of that of natural sunlight in Finland to virtually nil. On this basis, it is clear that the design of UV lamps for terrarium use must focus more precisely on the spectral characteristics of the UVB-1 range which produces vitamin D_3.

Materials and Methods

Fourteen lamps of various makes and models were obtained for testing purposes (see table 1). A Zoo Med ReptiSun 5.0 unit which had been used for 10 months was also included because it could provide general information about the declining of UV radiation of a high-quality lamp over a long period of time. Some of the lamps included (e.g. True-Light) are so-called full spectrum lamps and because of this, their irradiance in the UVB range will not be at the same level as actual UV lamps. Naturally this has to be accounted for when evaluating the results.

As a reference, the spectrum of the sun was also measured. The measurement was made when the sun was at its highest point of elevation in the southern sky of Finland and natural UV radiation is strongest. Measurement was made in Raisio, 8 kilometres northwest from Turku (60°28'60N 22°10'60E).

The lamps to be measured were borrowed from retailers or purchased for personal use. Anja Kairisalo kindly donated the 10 months old ReptiSun 5.0 unit. Rolf C. Hagen Inc. provided their own models: Exo Terra Repti Glo models 2.0, 5.0 and 8.0, as well as Reptile Super UV Daylight and Reptile Desert 7 % UVB, the latter two being manufactured by Energy Savers Unlimited.

As there was only one unit of each lamp, the statistical reliability of the measurements is weak (sample=1). Nevertheless, it represents quite well the situati-

Product	Power (W)	Manufacturer	Notes
ZooMed ReptiSun 5.0 UVB	14	Zoo Med Laboratories, Inc	
ZooMed ReptiSun 5.0 UVB (used)	15	Zoo Med Laboratories, Inc	10 months used, 12 hrs / day
Sylvania Reptistar	30	Sylvania	
Narva Reptilight	36	Narva	
R.C. Hagen Repti-Glo	40	Rolf C. Hagen Corp.	
R.C. Hagen Life-Glo	40	Rolf C. Hagen Corp.	Opening to concentrate and direct light beam
R.C. Hagen Exo-Terra Repti Glo 2.0	40	Rolf C. Hagen Corp.	
R.C. Hagen Exo-Terra Repti Glo 5.0	40	Rolf C. Hagen Corp.	
R.C. Hagen Exo-Terra Repti Glo 8.0	40	Rolf C. Hagen Corp.	
ESU Reptile Super UV Daylight	40	Energy Savers Unlimited Inc.	
ESU Reptile Desert 7 % UVB	40	Energy Savers Unlimited Inc.	Reflective foil to concentrate and direct light beam
Active UVHeat	100	Wild Inside	Type 'Flood', E27 socket
True-Light	36	"Manufactured for AD-Lux Oy"	full spectrum lamp 5500 K
True-Light Daylight 6000	15	"Manufactured for AD-Lux Oy"	full spectrum lamp 6000 K, E27 socket
Sun	-	-	Location: Raisio, Finland; 60°28'60N 22°10'60E, alt. 27 m. June 27 2001 13:08 EET DST. No clouds. UV-Index 5.6. Sun's elevation 52°32'

Table 1. General information.

on of a consumer purchasing a new lamp. When buying only one unit, the chance of consumer getting a faulty unit is the same as in this test. To eliminate obvious errors, all exceptional, inconsequent or otherwise suspicious measurement data was confirmed with the manufacturers.

All new lamps were pre-conditioned by using them in a normal terrarium lighting fixture for 100 hours, 12 hours a day. Prior to actual measurements, each lamp was preheated for 30 minutes to allow it to reach its nominal working temperature and to ensure lamp stability.

Measurements were made by Suomen Aurinkosimulaattori Oy/Solar Simulator Finland Ltd. The spectroradiometer used for all measurements was IL700A Research Radiometer, manufactured by International Light Inc., Newburyport, Massachusetts, USA. The measuring head used was an S-20 photomultiplier PM271D. The spectroradiometer is being calibrated on a yearly basis by wavelength and sensitivity. In order to control wavelength calibration, the device is quick-calibrated by measuring a HeNe laser's known wavelength of 633 nm before each session. Wavelength measuring accuracy is ±3 nm.

Measurements of spectral irradiance were made in a free field, at a distance of 30 centimetres from the surface of the lamp. Fluorescent lamps were measured at their centre point, perpendicular to the longitudinal axis of the lamp. In case the lamp had a fixed reflector or a particular aperture, the measurement was made from the main direction of radiation. Lamps with a European E27 socket were measured from the direction of base longitudinal axis at a distance of 30 centimetres from the face of the lamp.

Numerical analysis and spectrum diagrams of measured data were made with Microsoft Excel 2000. Measurement data shows measured irradiance (mW/m^2) at one nanometre resolution between 250–800 nm, 551 data points in all. These were imported to an Excel spreadsheet, converted to µW/cm^2, and irradiances on different wavelength ranges were integrated. Because of the lack of a fixed standard determining the boundaries of UVA, UVB and UVC ranges, the ranges commonly used in current literature were adopted. Due to quantized nature of measurement data, the following limits were used in analyses: UVA 320–399 nm, UVB 280–319 nm and UVC 250–279 nm. Visible light is taken to be between 400–749 nm, and near infrared to be 750–800 nm.

The basis for the calculation of the D_3 Yield Index was the action spectrum of 7-DHC to preD_3 conversion in human skin. The index was calculated in the 252–313 nm range by weighing the irradiance at each wavelength in accordance with the action spectrum. The effective irradiances thus obtained were summed over this range, and this value was finally adjusted to the reference by a suitable multiplication factor, resulting in the final D_3 index.

Results

General information about measured samples is listed in table 1. Lamps are numbered here for reference in other tables. Besides brand name, model, manufacturer or retailer, and nominal power, any additional information that may affect the results is given.

In table 2, irradiances as microwatts per square centimetre and percentage proportions of UVA, UVB and UVC from total irradiance are listed. Using equivalent values given by manufacturers, general comparisons to other models outside this test can be done. However, it has to be certified that the UV ranges have been specified with identical ranges: UVA 320–399 nm, UVB 280–319 nm, and UVC 250–279 nm.

Table 3 shows irradiances in the UVB range. Separate values have been calculated for the wavelength range that mainly contributes to vitamin D_3 photosynthesis (UVB-1, 280–304 nm) and for range above it (UVB-2, 305–319 nm) that may potentially destroy vitamin D_3. Bernard (1995) calls this range 290–300 nm as ”D-UV”, but in order to maintain consistency with the naming conventions (UVA, UVB, UVC), the sub-ranges of UVB are designated here UVB-1 and UVB-2. The ability of a lamp to efficiently produce vitamin D_3 can be evaluated by comparing values in table 3. The higher the irradiance of UVB-2 is in comparison to UVB-1, the higher the probability that UVB-2 radiation will start destroying cutaneous vitamin D_3.

Table 4 lists the D_3 Yield Index of the target and the percentage of UVB from total output for comparison. While calculating D_3 yield indices, the lack of accurate data made it impossible to take into account the above-mentioned possibility that weak radiation in the UVB-1 range, combined with strong radiation in the UVB-2 range, may cause photodestruction of vitamin D_3. Thus, if a lamp has a high UVB percentage but a weak D_3 Yield Index, it might suggest destruction of vitamin D_3. In this case it will be necessary to closely examine the spectral curve of the lamp at UVB/UVA crossover point in order to evaluate the situation.

Discussion

This kind of an extensive study brings forward many kinds of test results. Some of the measured lamps are obviously meant for a different purpose than being a sole light source of a terrarium. Measurement results of these lamps need to be handled as a separate group. For example, the UV spectrum of so-called full spectrum lamps and actual UV lamps cannot be compared. The lamps belonging to the former group are meant to produce visible light with as natural and uniform spectrum as possible. Their UV radiation – if any – is merely a by-product of any fluorescent lamp. These types of lamps should never be considered as the only light source for an animal requiring UV light. Equally, it can be said that lamps designed for maximum UVB radiation are not directly comparable with regular UVB fluorescent lamps. It should also be borne in mind that the sunlight used as reference has been measured at Finnish latitude (at summer solstice, when the sun is at its highest point of elevation). The natural habit of most terrarium animals is further to the south, where the radiation coming from the sun penetrates the atmosphere almost vertically and thus has to pass through a much thinner layer of ozone and air. This has a major effect on the shortest wavelengths of UV irradiation reaching the surface of the earth. In these measurements, the reference sun appears exceedingly weak, especially in the UV range, when compared to the situation in the natural habitat of many terrarium animals. Another issue that may affect the D_3 Yield Index is the fact that the spectrophotometer’s sensitivity had to be reduced during the measurement of reference sunlight because the total radiation flux of the sun was higher than that of the lamps by a factor of over 200. This results in a situation in which the sensitivity of the sensor might be insufficient in the extreme low end of the spectrum. This may cause the spectrum curve to fall off too early. Measurement with a specialised UV meter might have obviated this problem, but that would have been impractical within the scope of this study.

Distribution of UV light

When comparing the distribution of ultraviolet light in the UVA, UVB and UVC regions, the strong emphasis of UVA can be seen in all results (see table 2). Many of the lamps have over 30 % of their total radiation in the UVA range. Although this may be detrimental to vitamin D_3 synthesis, according to some reports it might have a positive effect on reptile behaviour (Gehrmann, 1994). There is not much research material available on this subject. Human studies have given contradictory results. In humans it has been found out that UVA can cause eye damage (for example yellowing of the lens of eye), premature aging of the skin, and changes to the immune response. Because of this, excessive amounts cannot be recommended for animals either. In any case, the UVA irradiance of all lamps measured is only about 1–2 % of that of the sun, hardly a cause of concern in that respect.

A few lamps clearly stand out from the rest with their almost total lack of ultraviolet light. Of these, True-Light lamps are obviously not UV lamps, although their retailer has sometimes recommended them for this purpose. The lamp models Repti Glo, Life-Glo, Exo-Terra Repti Glo 2.0, and ESU Reptile Super UV Daylight, emit only a few percent of their radiation in the UVA range, with even less in the UVB range. Active UVHeat lamp also stands out with its rather low percentage of UVB radiation; this is, however, a bit misleading, since the nominal power of this lamp is significantly higher than that of any other. Although its irradiance in UVB region is quite high, this is still not a proof of its high capability to promoting photosynthesis of vitamin D_3, as shown later.

When evaluating the proportion of UVB radiation only, Zoo Med ReptiSun 5.0 and Sylvania Reptistar stand out. Over 6 % of their total irradiance is in the UVB range. Narva Reptilight and R.C. Hagens Exo-

Product	UVA		UVB		UVC	
	μW/cm²	%	μW/cm²	%	μW/cm²	%
ZooMed ReptiSun 5.0 UVB	48	31.9 %	10	6.8 %	0	0.0 %
ZooMed ReptiSun 5.0 UVB (used)	40	31.3 %	8	6.6 %	0	0.0 %
Sylvania Reptistar	59	31.2 %	12	6.1 %	0	0.0 %
Narva Reptilight	37	23.2 %	7	4.4 %	0	0.0 %
R.C. Hagen Repti-Glo	4	1.7 %	1	0.6 %	0	0.0 %
R.C. Hagen Life-Glo	3	0.9 %	1	0.3 %	0	0.0 %
R.C. Hagen Exo-Terra Repti Glo 2.0	1	1.0 %	1	0.3 %	0	0.0 %
R.C. Hagen Exo-Terra Repti Glo 5.0	33	21.2 %	5	3.4 %	0	0.0 %
R.C. Hagen Exo-Terra Repti Glo 8.0	65	35.6 %	8	4.2 %	0	0.0 %
ESU Reptile Super UV Daylight	7	5.7 %	1	1.0 %	0	0.0 %
ESU Reptile Desert 7 % UVB	38	26.2 %	0	0.3 %	0	0.0 %
Active UVHeat	296	22.6 %	16	1.2 %	0	0.0 %
True-Light	19	11.9 %	1	0.5 %	0	0.0 %
True-Light Daylight 6000	2	1.3 %	0	0.0 %	0	0.0 %
Sun	3403	8.1 %	118	0.3 %	0	0.0 %

Table 2. Distribution of light.

Terra Repti Glo, models 5.0 and 8.0, make up another group with their 3–4 percent UVB proportion. The rest of the lamps produce only extremely small amounts of UVB.

Health hazard of UV irradiation

The Finnish Ministry of Social Affairs and Health has issued decree No: 1474 (Dec. 16. 1991) with regard to the maximum exposure to non-ionising radiation. According to this decree, the biologically weighted effective energy density of ultraviolet radiation on eye or skin must not exceed 50 J/m^2 per day.

The UV radiation of Active UVHeat exceeds this figure and it may therefore constitute a health hazard. At a distance of 30 cm, the limit is reached in 40 minutes; at 1.5 meters in 390 minutes. In the home, the Active UVHeat lamp must be shielded so that its light is screened from the areas where there are people for long periods of time. The terrarium must have a shaded area available for all animals at all times. The same risk is present also with other high output UV lamps. With other lamps, the estimated safe exposure time at 30 cm distance is about 1.5 hours. A single sheet of window glass secures adequate protection from harmful radiation. Such glass filters 22 % of UVA and 96 % of UVB radiation (Gehrmann, 1987).

D_3 Yield Index

The percentage of UVB radiation from the total output has often been taken as an indicator of the ability of a lamp to maintain vitamin D_3 photosynthesis in the animal skin. According to research made on human skin, the issue is not as simple as that. MacLaughlin *et. al.* (1982) showed that the action spectrum of vitamin D_3 photosynthesis is extremely narrow (fig. 1). Vitamin D_3 production takes place mainly in the wavelength range 295–300 nm, while the UVB range is generally specified 280–320 nm. This difference is significant especially at the top of the range, where vitamin D_3 production ceases, but photodestruction by longer wavelength radiation still continues. This makes the use of UVB irradiance figure by itself a poor indicator of the effectiveness of the incident light in photosynthesising vitamin D_3 in animal skin.

Use of the D_3 Yield Index as a basis for evaluation of UV lamps gives a possibility to compare very different types of lamps with consistent criteria. The D_3 Yield Index turns the attributes of a spectrum curve, that are otherwise difficult to compare, into an easily manageable and understandable form even for a novice keeper; they indicate with an unambiguous value the efficiency of a lamp to promote photosynthesis of vitamin D_3 and by that, indirectly ensure sufficient level of calcium metabolism.

Because the action spectrum for vitamin D_3 photodestruction was not available, it was not possible to evaluate the effect of this process on the D_3 Yield Index. More research is needed to resolve this. An *in situ* analysis of 7-DHC and its reaction products is also required to confirm their relation to the D_3 Yield Index.

It should also be noted that the formula for calculating the D_3 Yield Index has not been tailored to compensate for power differences between lamps. Therefore, in case there are two otherwise identical lamps the one with higher nominal power receives a higher index figure, proportional to the power difference.

The D_3 yield indices calculated on the basis of measurements of this study illustrate the fact that the

	Irradiance µW/cm²	
Product	UVB-1 280-304 nm	UVB-2 305-319 nm
ZooMed ReptiSun 5.0 UVB	2.057	8.232
ZooMed ReptiSun 5.0 UVB (used)	1.717	6.663
Sylvania Reptistar	0.497	10.982
Narva Reptilight	1.302	5.825
R.C. Hagen Repti-Glo	0.089	1.052
R.C. Hagen Life-Glo	0.083	0.863
R.C. Hagen Exo-Terra Repti Glo 2.0	0.000	0.467
R.C. Hagen Exo-Terra Repti Glo 5.0	0.635	4.659
R.C. Hagen Exo-Terra Repti Glo 8.0	0.780	6.914
ESU Reptile Super UV Daylight	0.014	1.103
ESU Reptile Desert 7 % UVB	0.000	0.443
Active UVHeat	0.815	14.647
True-Light	0.030	0.693
True-Light Daylight 6000	0.000	0.003
Sun	0.000	117.699

Table 3. Irridiance.

percentage of UVB from total irradiance is not necessarily directly related to the capability of a lamp to promote vitamin D_3 photosynthesis. Most clearly this can be seen in the case of Sylvania Reptistar; although 6 % of its radiation is UVB, its D_3 Yield Index is only mediocre. When examining the spectrum of this lamp (published elsewhere in this magazine), it can be seen that its irradiance is almost zero in the range 290–300 nm, which is the most important range for the index.

Similarly misleading, but in the opposite direction, is the UVB proportion of Active UVHeat: only 1 % – yet its D_3 Yield Index is approximately the same as for Sylvania Reptistar. In this case, the proportion of UVB from the total amount of radiation is extremely small, but its irradiance is very high. The fact that the total irradiance of Active UVHeat is many times higher, 1308 µW/cm² as opposed to Reptistar's 188 µW/cm², makes the percentage comparison alone look insufficient.

Of all the lamps measured, the best contributor to vitamin D_3 photosynthesis in skin is Zoo Med ReptiSun, with a D_3 Yield Index of 439. This result can be considered especially noteworthy for the fact that the lamp in question is only a 14 W unit, while other units in the study have a nominal power of 30–40 W. The spectrum of ReptiSun begins very low in the UVB range and the spectrum curve rises steeply. In the most sensitive wavelength for vitamin D_3 synthesis, 295 nm, for example, the radiation of ReptiSun is already 1.8 times stronger than that of the next best lamp.

The second best lamp, a Zoo Med ReptiSun unit that had been used for 10 months, does not show remarkable weakening of UVB radiation. While examining the full spectrum, it can be seen that the irradiance of the lamp has dropped constantly throughout the whole spectrum. This means that the UVB radiation of a lamp does not cease abruptly, as is sometimes suggested, but seems to get gradually weaker along with the visible light. On this basis a recommendation to replace the UV lamp twice a year due to alleged fading of UVB radiation is at least to some extent unwarranted. The conclusion is of course based only on one individual lamp; differences due to manufacturing tolerances etc. are entirely possible. A detailed research with a larger sample would be required to confirm this issue.

The next best lamp, Narva Reptilight, is also very efficient in promoting vitamin D_3 synthesis with a D_3 Yield Index of 284. Additionally, its spectrum is exceptionally beneficial; radiation at 315–335 nm range which potentially destroys vitamin D_3 is very low.

Next comes a group of four lamps, the results for which are rather equal. Their D_3 yield indices are already less than half of that of the best product. In this group, the case of Sylvania Reptistar is interesting. Even though its irradiance in UVB range is the third highest of all tested units, its D_3 Yield Index is only modest. Its spectrum curve starts to rise only at about 300 nm; therefore, the main proportion of its radiation is concentrated in the UVB-2 and UVA ranges, in which strong irradiation is known to be detrimental to the production of vitamin D_3.

Another sample that attracts attention in this group is Active UVHeat. The spectrum of this lamp is almost a pure line. In the wavelengths where radiation exists, it is very strong. In other areas radiation is at the same level as for the 14 W ReptiSun unit. There is only one single peak in the UVB-1 range, at 302–304 nm – this establishes the D_3 Yield Index of this lamp at a reasonable level. However, its spectrum has another peak, over

Product	D3 Yield Index	UVB %
ZooMed ReptiSun 5.0 UVB	439.3	7 %
ZooMed ReptiSun 5.0 UVB (used.)	367.7	7 %
Narva Reptilight	283.7	4 %
R.C. Hagen Exo-Terra Repti Glo 8.0	190.2	4 %
Active UVHeat	165.3	1 %
Sylvania Reptistar	157.5	6 %
R.C. Hagen Exo-Terra Repti Glo 5.0	150.8	3 %
R.C. Hagen Repti-Glo	22.4	1 %
R.C. Hagen Life-Glo	19.5	0 %
ESU Reptile Super UV Daylight	11.2	1 %
True-Light	9.2	1 %
R.C. Hagen Exo-Terra Repti Glo 2.0	2.2	0 %
ESU Reptile Desert 7 % UVB	0.5	0 %
True-Light Daylight 6000	0.0	0 %
Sun	1000.0	0 %

Table 4. D_3 yield index.

10 times higher, at 313 nm and beyond that generally rather high irradiance values which may contribute to photodestruction of existing vitamin D_3 in skin.

The rest of the measured lamps are disappointing in their D_3 Yield Indexes. Even the best (Rolf C. Hagen Repti Glo and Life-Glo) of these units have an index figure that is only 5 % of that of the ReptiSun unit. Lamps in this group cannot be recommended for use as UV lamps with a purpose to promote vitamin D_3 photosynthesis in skin.

Both True-Light units also belong to this group, and apparently their purpose is not to be actual UV lamps. They are full spectrum lamps that presumably have not had the amount of UVB radiation as one of their main design criteria; instead they are intended to have as constant and natural spectrum in visible light as possible.

The Reptile Desert 7 % UVB, manufactured by Energy Savers Unlimited (ESU), turned out to be a disappointment. Despite its name, the unit only produces 0.3 % UVB radiation and its D_3 Yield Index is only 0.5.

The sunlight that was measured as a reference is in its own league, and naturally the result would only get better if measured closer to the equator: the D_3 Yield Index of the sun (1000) is over twice to that of the best of all the units tested. Due to the manifold radiation strength of the sun across the entire visible spectrum, its proportion of UVB is only 0.3 %.

When examining the results of the reference sunlight it has to be kept in mind that most reptiles kept in terrarium originate from areas far south from Finland. Therefore, the radiation of the sun measured in Finland is not an appropriate reference for determining adequate strength of UVB radiation, except for evaluating the light supply for domestic outdoor enclosures. Realistic reference can only be obtained by measuring the radiation of the sun in the natural habitat of the animal. To verify the results published here, and to establish a common baseline, it would be necessary to do an analogous measurement with compatible equipment near the equator.

However, the D_3 Yield Index of the sun should not be considered as an absolute target figure since the irradiation measured here can only be achieved in a short time frame at noon in midsummer. Artificial lighting produces a uniform level of radiation during the time lamps are switched on. In the morning and evening, and during seasons other than summer, the radiation from sun penetrates the atmosphere in an inclined angle due to the lower elevation of the sun. Effectively thicker layer of ozone filters more ultraviolet light, and consequently the relative strength of UVB radiation of sun decreases rapidly. This is naturally equally applicable to all parts of the globe.

The sensitivity of the measurement device had to be reduced during the measurement due to the strong radiation of the sun in the visible range. This may have led to a premature cut-off at the very beginning of the spectrum that may affect the D_3 Yield Index of the sun.

In conclusion, there are distinct differences in the suitability of different lamps to promote vitamin D_3 photosynthesis in skin. In many cases, the percentage of UVB stated by the manufacturer is so close to measurement values that any differences are most likely caused by variations in calibration and spectral sensitivity of measurement equipment. However, in some cases larger discrepancies were found. For this reason, the UVB percentage given in the retail packages of products should be looked upon with appropriate reservations.

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Author:

Jukka Lindgren, Humikkalantie 101 A 2, 00970 Helsinki, Finland. Tel. +358 40 770 1036. Email: testudo@testudo.cc or jukka.lindgren@herpetomania.fi.