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Could Titans Produce Enough Energy to Sustain Themselves?

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Abstract
This paper discusses whether or not Titans could produce enough energy photosynthetically to sustain themselves, and thus whether they could survive. It was found that the Titans always produced below 20% of the energy that they would require, through photosynthesis alone, regardless of the Titan's size. This suggests the Titans must have another energy source alongside photosynthesis. Beware possible spoilers for Attack on Titan season 1 and 2.

Introduction
In the Japanese anime *Attack on Titan*, Titans are giant humanoid creatures that have pushed humanity to the brink of extinction. The Titans mostly resemble male humans, without reproductive organs, and all have certain disfigurements such as enlarged heads [1]. Specifically in this paper the 'Normal' Titans will be discussed, simply known as Titans.


Figure 1 - Titans from 'Attack on Titan' (Anime) [2]

The Titan's sole purpose is to eat, and thus kill humans, while disregarding other sources of nutrition. However, in season 1 of the anime it is stated that the Titans do not use humans for energy as they have no digestive tract [1]; just regurgitating the humans when their stomach is full. Therefore, it is theorised that the Titans must photosynthesise, since they have managed to survive for 100 years without feeding on any form of life. This paper investigates the possibility of a Titans' energy requirement being solely provided by sunlight.

Energy Expenditure
In order to find out if the Titans do produce enough energy to sustain themselves, the total daily energy expenditure (T_D) is calculated. The T_D is calculated with the Harris Benedict equation [3]:

$$T_D = B_{MR} \times AF \quad (1)$$

Where B_{MR} is the basal metabolic rate and AF is the activity factor. The activity factor is dependent on the exercise level of the Titan. The majority of Titans remain active by walking throughout the whole day. Hence, it can be said that their exercise level is heavy, thus the activity factor is approximately 1.725 [3]. The basal metabolic rate is calculated using the following equation [4];

$$B_{MR} = (13.75 \times M) + (5 \times H) - (6.76 \times A) + 66 \quad (2)$$

Where M is the mass in kilograms, H is the height in centimetres and A is the age. Assuming the Titans have an energy expenditure similar to that of a young adult, their age is assumed to be approximately 25. The paper considers the lower class of Titan to begin with, which stand at a height of 3m (300cm). The mass of a Titan is more speculative than the other values; in season 1 of the anime Hange Zoë notes that a Titan's body is abnormally light compared to what you would expect. However, as there has not been an explanation yet, for simplicity the mass is estimated from the BMI of the Titan [5]:

$$BMI \times H^2 = M \quad (3)$$

The height in this equation is in metres, thus is 3m, and it is assumed that the Titans have an ideal BMI of approximately 22 [6]. Substituting the values into Equation 3 gives a mass of 198kg. Using this mass, the height of 300cm and age of 25, the values can then be substituted into Equation 2. This gives the B_{MR} for a 3m tall Titan to be approximately 4119.5 kcal day^{-1}. Equation 1 states the T_D is the product of this value and the AF thus multiplying this B_{MR} by the AF estimated to be 1.725 above, gives a T_D of 7106.14 kcal day^{-1}. Therefore, in order to meet their energy requirement the 3m tall Titans must produce 7106.14 kcal (2.97×10^7 J) every day by photosynthesis.

Photosynthetic energy produced

To have photosynthetic ability the Titans must have some organelle in their cells that absorbs light, then utilises this light to form carbohydrates. For simplicity it is assumed that this photosynthetic cell is equivalent to plant cells with chloroplasts. Plant cells typically only convert 1-2% of energy supplied by light into usable energy in the form of carbohydrates [7]; therefore, this paper will generously estimate the conversion to usable energy to be 2%, to see if the Titan produces enough energy with the highest percentage. An issue with this theory would be how the Titan's acquire the water needed for photosynthesis. This could raise another limitation to the energy conversion, however this paper will not address this issue and simply state if the Titans could obtain the water, could they sustain themselves.

The amount of energy stored in a Titan's skin can be estimated from the stellar flux. As Attack on Titan is meant to be a dystopian future on the Earth, the flux will be the Sun's. At the Earth, the solar flux has a value of 1370 J s^{-1} m^{-2} [8], therefore the total light energy to hit the skin of a Titan will be the product of the flux (F) with the total time (t) the Titan spent in sunlight and the surface area of the Titans' skin. Assuming a 14 hour sunlight period gives a time of 50400s. To find the surface area of the skin the Mosteller formula was used, which relates the body surface area (B_{SA}) to the height (in cm) and mass (in kg) of the Titan [9];

$$B_{SA} = \sqrt{\frac{M \times H}{3600}} \quad (4)$$

Using the mass as found previously to be 198kg, and the height as 300cm, the B_{SA} was found to be 4.06 m^2. The total energy (E) incident on the 3m Titan then can be found;

$$E = F \times B_{SA} \times t \quad (5)$$

Substituting in the flux (1370 J s^{-1} m^{-2}), body surface area (4.06 m^2) and an arbitrary time of 14 hours (50400 s), the energy is calculated to be 2.80×10^8 J of maximum energy. As previously stated, if only 1-2% of this energy is converted to usable energy this means, at most, from a 14 hour day a 3m Titan would produce 5.61×10^6 J of energy. This is almost five times less than then energy calculated to sustain the Titan, 2.97×10^7 J, only producing 19% of the energy the Titan needs. Even if the Titan produced energy 24 hours a day it would still only produce 32% of the energy required to sustain it.

This can also be used for the three other Titan types, the medium (7m), large (15m), and colossal (60m) Titans. The energy produced by each of these becomes increasingly insufficient as the Titan gets taller, with only 15%, 12%, and 6% respectively. Therefore, it can be safely assumed that if the Titans' energy production is similar to that of plants, they would have died out almost instantly. Therefore the reason they are able to sustain themselves may be due to their unusually light body mass. As the energy expenditure is related to the mass of the Titan, this may be feasible. However the mass would have to be a significantly small fraction than the mass one would expect. This would raise questions on whether the Titans would have the strength to destroy buildings as they effortlessly do.

Conclusion

To conclude, by modelling the Titans' skin as the equivalent of plant cells producing similar energy by the same means, the Titans would not survive. All of the Titans - 3m, 7m, 15m, and 60m - would produce a very small percentage (19%, 15%, 12%, and 6% respectively) of the energy they would require to sustain themselves. Therefore, unless the mass of the Titans plays a significant role in improving the supply/demand energy ratio, then the Titans are unfeasible creatures. However, if the skin utilised almost 100% of the energy then there may be a higher possibility that the Titans could exist.

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