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SHORT COMMUNICATION

Self-irrigation in the desert rhubarb *Rheum palaestinum* – a response to Khammash

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Khammash (2016) argued that self-irrigation occurs in the desert plant *Rheum palaestinum* Feinbrun, by collecting dew with its unique 3D leaf morphology and its extremely large leaves rather than collecting rainfall. We agree that collecting dew indeed has a theoretical potential to improve the plant's water economy. However, we suggest that collecting dew can act as an additional mechanism for collecting water rather than an exclusive one. The unknown relative contribution of these two parallel functioning self-irrigation mechanisms to the water economy of the desert rhubarb should be further studied.

Key words – Dew, desert rhubarb, rainfall, *Rheum palaestinum*, self-irrigation.

INTRODUCTION

We were pleased to see that our original hypothesis (Lev-Yadun et al. 2009), demonstrating how the rare endemic desert plant *Rheum palaestinum* (Polygonaceae) self-irrigates by collecting rain water with its large and wrinkled leaves, has stimulated further research and additional hypotheses on its mechanism of self-irrigation (Khammash 2016). Our study was not aimed at solving all the mysteries of the biology of desert rhubarb's unique leaf morphology, but rather at demonstrating that such striking, large leaves, with their 3D hydrophobic folds that mimic mountainous drainage systems, which are atypical of desert plants, serve in rainfall collection, transport, and self-irrigation. The ecological/evolutionary logic of our hypothesis was that under the extreme arid conditions of its habitat, in the in Jordanian desert and highlands of the Negev Desert in Israel (Feinbrun 1944, Zohary 1966), with average annual rainfall of only c. 75 mm (Israel Meteorological Service 1987), any method of improving the plants' water economy will be of great ecological advantage.

Rheum palaestinum grows during the rainy winter in mountainous desert areas and produces 1–4 large round leaves that are tightly appressed to the ground, forming a large rosette of up to about 1 m^2. We found that the unique 3D morphology of its large leaves that we described in general but not quantitatively, and demonstrated with pictures, assisted by its very hydrophobic cuticule, helps the plant to collect significant amounts of rainfall and funnel it into the soil around its deep central root. We measured the seasonal course of leaf growth, examined the area of wet soil surrounding the root after actual, simulated rain events, and modelled the water harvesting capacity using seasonal plant leaf area growth and the regional average weekly precipitation. We demonstrated experimentally that even in the lightest rain, water flows above the sunken major leaf veins to their base, where it irrigates the deep vertical root. We calculated that a typical plant can harvest > 4,100 cm^3 of water per year, and enjoys (after accounting for water spillage to the sides and missing the early rains that occur before leaf emergence and till its full growth) a net water regime equivalent to c. 427 mm/year, similar to the precipitation regime of the Mediterranean climate. Because typical desert plants do not collect water like this, and because of water evaporation and runoff, we calculated that *R. palaestinum* gets 16 times more water than many other plants growing in the same habitat. Moreover, the largest observed *R. palaestinum* individuals can harvest ten times more rainfall than average-sized plants, which probably caused a strong selection for larger individual *R. palaestinum* plants. Our study was the first demonstration of such self-irrigation by large leaves of a desert plant, creating a leaf-made mini oasis (Lev-Yadun et al. 2009).

Khammash (2016) suggested that the complex leaf morphology of *R. palaestinum* plants protects against excessive transpiration by self-shading, and that the 3D leaf morphology significantly increases the surface area to maximize dew condensation, mostly on the lower surface of the leaf and to a lesser degree on its upper surface. He posited that the unique 3D leaf morphology of *R. palaestinum* evolved not to collect rainfall but rather to trap sub-foliage condensed dew.

COMMENTS

We have several comments concerning the interesting hypotheses and findings presented by Khammash (2016) and

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hope that this discussion will stimulate further research of this unique species and reveal other water harvesting desert plants in other deserts of the world:

(1) Khammash (2016) presented elegant quantitative descriptive data on leaf morphology, derived from the use of a 3D simulation software. The simulations provided important quantitative data on the rate of increased leaf area as the result of the unique 3D structure, but provided no actual quantitative data of above-leaf water harvest or below-leaf dew condensation. Therefore, some of the conclusions concerning both dew and rainfall harvest were not based on actual results.

(2) From the large number of plants we examined in the field, it is clear that many do not grow on horizontal surfaces but rather occupy small depressions, slopes, or grow adjacent to boulders. Therefore, for many *R. palaestinum* plants, the simulation of drainage (fig. 3 in Khammash 2016) is much too simplistic and does not cover the full repertoire of rainfall harvest capability. We appreciate the effort to calculate the loss of harvested rainfall by drainage to the side *via* leaf margins (we estimated total water loss and missed rainfall in the early winter to be 20%), but the actual loss should be measured in the field in a way similar to our measurements of actual and simulated rainfall (e.g. Lev-Yadun et al. 2009). Moreover, when we calculated the potential water harvest of these plants compared to other plant species in the region, and its advantage because of its unique leaves, we also took into consideration field data in Hillel & Tadmor (1962) that because of evaporation of rainfall from the soil surface and of runoff, only 35% (the equivalent of 26 mm rainfall) of the rainfall penetrates the soil and is available to plants in that area. The significant rate of evaporation in the desert must also be taken into consideration when the minute amounts of dew in that region (see below) are considered, information not accounted for by Khammash (2016).

(3) Estimating the potential contribution of dew condensation by Khammash (2016) is most valuable. However, to our mind, self-irrigation of *R. palaestinum* by condensation is not exclusive as posited by Khammash (2016) but, if functional, it acts as a parallel mechanism to harvesting rainfall (e.g. Lev-Yadun et al. 2009). Khammash (2016) stated "A simple leaf morphology can effectively drain rainwater without the need for wrinkles". We disagree with this statement because, as we have shown, the 3D leaf morphology with its water-repelling ability (probably by its waxy and hydrophobic cuticule, which was not studied chemically or otherwise), directs the water flow along the sunken leaf veins to irrigate the soil above and around the thick vertical root, where water penetrates deep soil layers and does not evaporate. With a flat leaf, in strong rain events, the water may flow in various directions and most of it may reach the soil in the leaf's peripheral area, from where it apparently will join the general runoff rather than contribute to the plant's water economy; in the case of light rains the small amounts of water will evaporate from the soil surface with no contribution to the plant's water economy.

(4) Based on 3D and other morphological data, with no new experimental data, Khammash (2016) rejected our quantitative evidence of rainwater collection. However, they do not present any quantitative experimental evidence for the amount of water that may be condensed under the leaves or on their upper surface, and without showing that condensed dew causes water infiltration into the soil down to the plant's deep root. Availability of such collected water to the plant must be proved before one can hypothesize on the evolution of leaf morphology.

(5) The environmental conditions at the study site in Jordan were not presented in detail. From the results given (Khammash 2016), one may guess that the soil substrates were either sand or rocky/stony. In sandy soils water infiltration rate is high with almost no water runoff. This is very different from loess soils in the Israeli habitat, where infiltration is minimal and runoff is maximal. This may explain differences in measurement, results and local adaptations.

(6) In the Negev desert, the annual cumulative amount of dew ranges between 17 and 30 mm occurring in events of about 0.07–0.12 mm/night in the relevant months (Zangvil 1996) but not over 0.35 mm/night (Evenari et al. 1982). Thus, during January–April, the relevant months for *R. palaestinum*, the maximal potential dew harvest does not exceed 6–10 mm, i.e. much lower than the potential rainfall harvest.

(7) The self-shading by the ridges on the upper sides of the leaves calculated by Khammash (2016) from his simulation

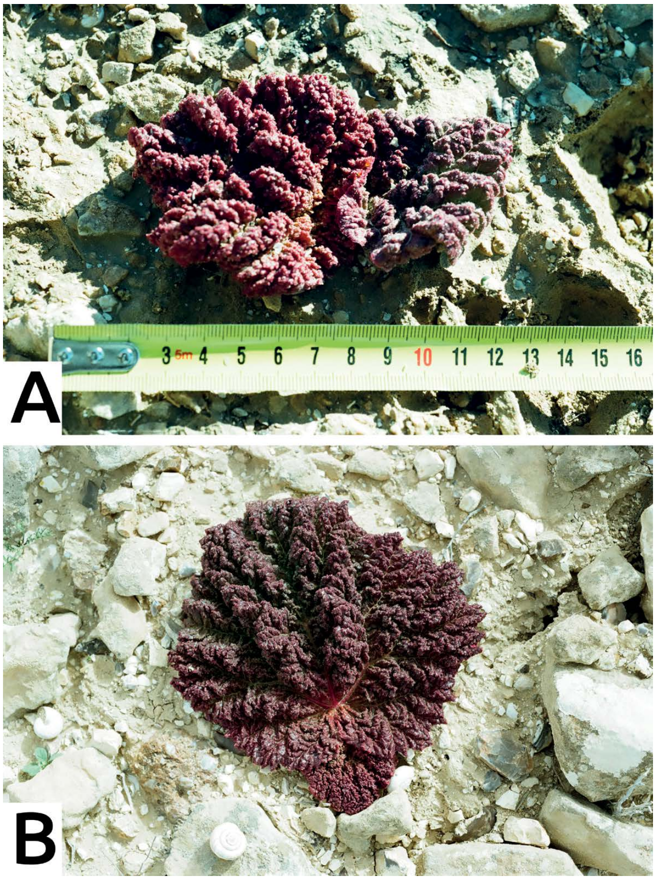

Figure 1 – *Rheum palaestinum*: A, typical red and still folded young leaves; B, an expanding red leaf. Photographed by Simcha Lev-Yadun, Mount Ramon, Negev Highlands.

may be a double edged sword. We found that the leaves of this hemicryptophyte emerge from the ground and grow in size mostly during January–March. The mean temperature of the coldest month in the Negev Desert highlands is 9.3°C (Evenari et al. 1982), meaning that it might be colder in certain days, so that self-shading may hamper plant growth and photosynthesis during January and February and, probably, even early March when the leaves tend to grow. Various Near Eastern species, including plants in the warmer coastal plain, track the sun during the winter and spring in order to become warmer (Koller 2000). Low temperatures may imbalance the photosynthetic system resulting in the production of reactive oxygen species (ROS) causing cellular damages (Gould et al. 2002). A common solution to overcome ROS damage under low temperatures is to express anthocyanins that scavenge ROS, i.e. anthocyanins are capable of neutralizing H_2O_2, when the temperature is too low for enzymatic antioxidant systems (Hughes 2011). Indeed, many young *R. palaestinum* leaves are red (fig. 1), indicating the need to warm the leaves rather than to shade and cool them. In our view, the 3D leaf morphology is not aimed at shading, but rather at collecting rain water as we proposed originally (Lev-Yadun et al. 2009).

CONCLUSIONS AND FURTHER RESEARCH

In our view, the major evolutionary driver behind the unique 3D morphology and leaf size in desert rhubarb, *R. palaestinum*, is collecting rain water for self-irrigation *sensu* Lev-Yadun et al. (2009). We agree with Khammash (2016) that collecting dew has a potential of increasing plant fitness under the highly arid conditions of its habitat. However, there is no reason why these hypotheses should be exclusive rather than additive. The positive contribution of dew collection probably results from allowing stomata to open without much water loss, because of the high water potential near the leaf surface. This prevails before evaporation of the dew, an effect that likely exceeds actual dew water harvest and root irrigation. Clearly, more measurements of the amount of collected dew are required in order to evaluate their relative contribution to the plant's water economy. The unknown relative contribution of these two self-irrigation mechanisms of the desert rhubarb should be studied. All other aspects such as potential self-shading (Khammash 2016) or red winter coloration shown here seem to be of lesser significance when compared to adaptations related to water harvest.

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