Epigenetic Regulation on Plant Stress Memory

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Abstract

Plants are sessile organisms; they cannot move like animals when the environment is not favorable. Therefore, plants need a mechanism to cope with environmental changes. For example, when a plant experiences stress, like water deficit, it will employ a certain mechanism that allows the plant to survive the next exposure (see Fig. 1), often referred to as "Epigenetic" regulation. By application, epigenetics deals with the changes of the level of the gene expression without change in the DNA sequence, by DNA methylation, histone modifications, and or small RNA regulation. Plant epigenetic regulation is related to the Lamarckian theory of evolution. Lamarck's (1744 – 1829) discredited theory of how transgenerational memory could be passed down through generations became one possible explanation for how plants become more resistant to future stress through acquisition of memory (see Fig. 2). Basically, an unnecessary gene (stress gene) is turned off. However, during stress, plant cells need to reactivate the genes by removing silencing marks, but the longer it is activated, the more prone the plant is to stress. The learning process can be induced and referred as priming. In the basic mechanism of priming, the histone demethylase enzyme unwinds the specific DNA regions that contain stress genes and remove the silent marks; thus it can be expressed more rapidly to tackle unfavorable condition compare to unprimed plants (consult the Figure 3). Remarkably, this working model of epigenetic transgenerational memory has also been applied for generating resistant plants with the same epigenetic mark by tissue culture propagation technique, which had been impossible to achieve previously (see Figure 4).

Histone Mark and Working Model on Plant Memory

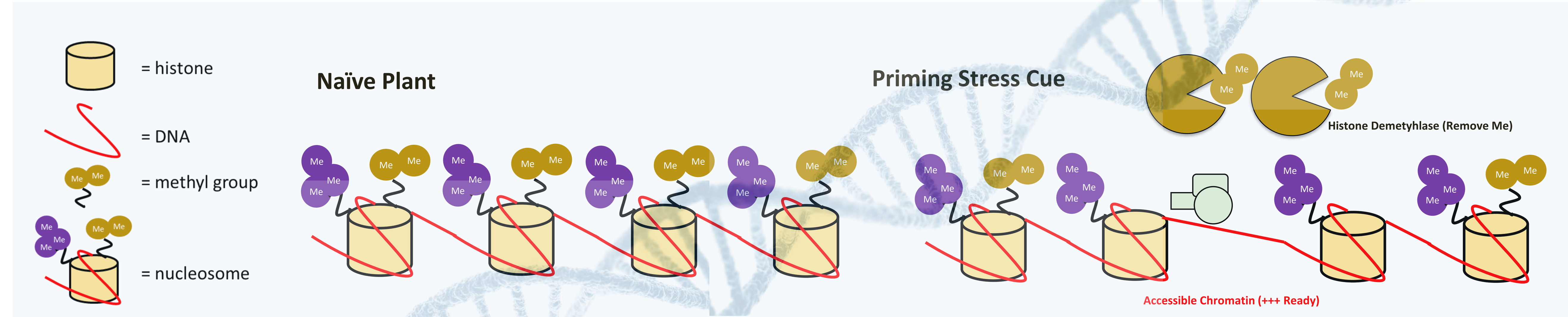

Fig. 3. The working model on plant stress memory by histone modification in primed plant (with stress experience) versus naïve plant (lack of stress experience). In primed plants, repressive mark on stress gene(s) is removed by histone demethylase enzyme; thus the chromatin is accessible and gene(s) is rapidly activated when the stress is present.

Connection of Stress, Learning, and Memory in Plants

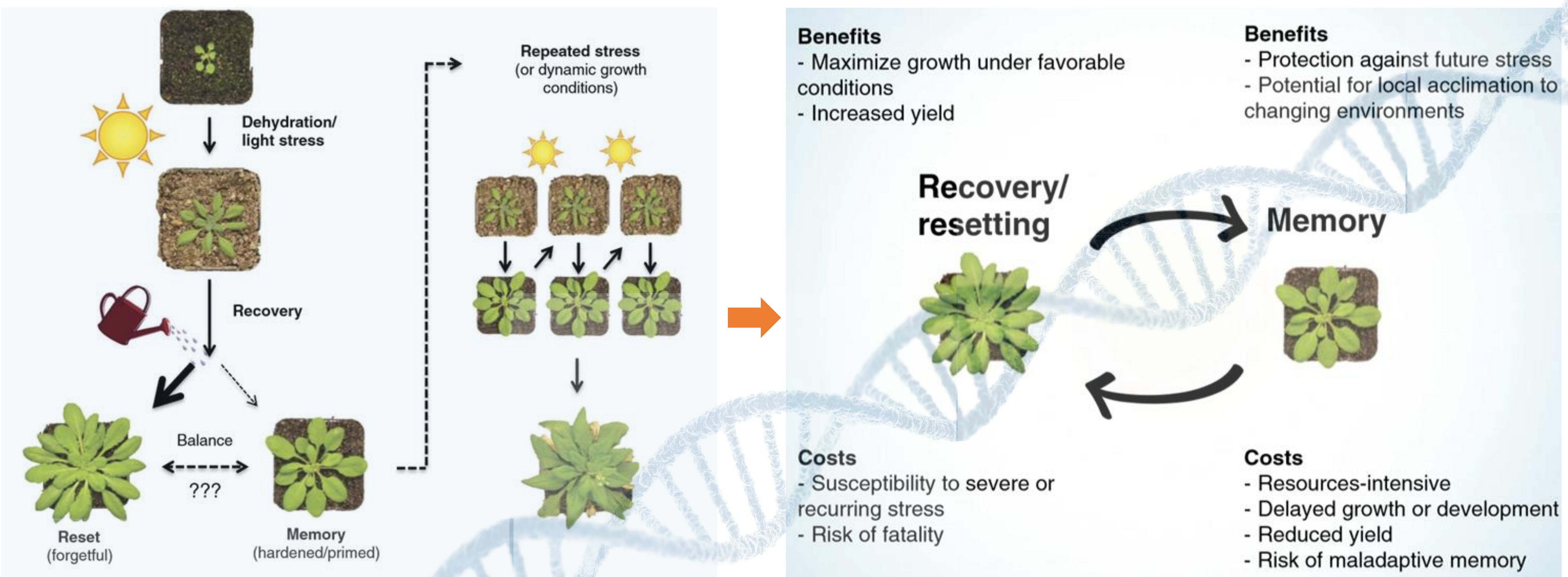

Fig. 1. A. Balancing model of recovery and memory formation. Plant makes a balance to create or reset memory. Both resetting and creating a memory have costs and benefits. Resetting is more dominant but repeated stress will tend to result in memory formation. Created by Crisp et al. (2012).

Application of Epigenetic Transgenerational Plant Stress Memory

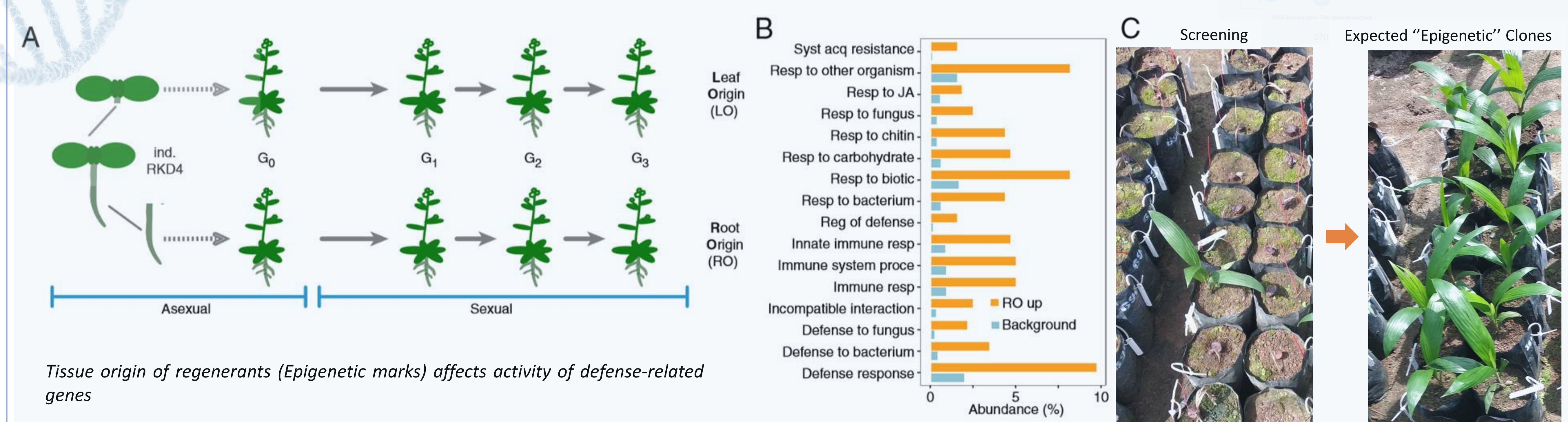

Fig. 4. To maintain epigenetic marks (resistant memory) plant need to be regenerated by special pathways. Propagation of individual that has excellent memory through seeds and tissue culture is impossible due to the resetting process in the genome during the development; thus the progeny lose their memory from parent. By introducing embryo gene *RKD4* scientist are now able to multiply plants with desirable characteristics and produce same clone plus maintain the memories from parent (refer to fig's 4A and 4B). This technology could be applied to propagate individual variants that resist disease. For instance, in Fig. 4C oil palm seedlings screened against major devastating rot disease (caused by *Ganoderma boninense*), and only one of 10,000 plants is resistant to it. By epigenetic transgenerational memory, it is possible to propagate the resistant plant and produce uniform progeny with the same resistance. Fig's 4A and 4 B Created by Wibowo et al. (2018).

Connection of Lamarck's Theory in Transgenerational Plants Stress Memory

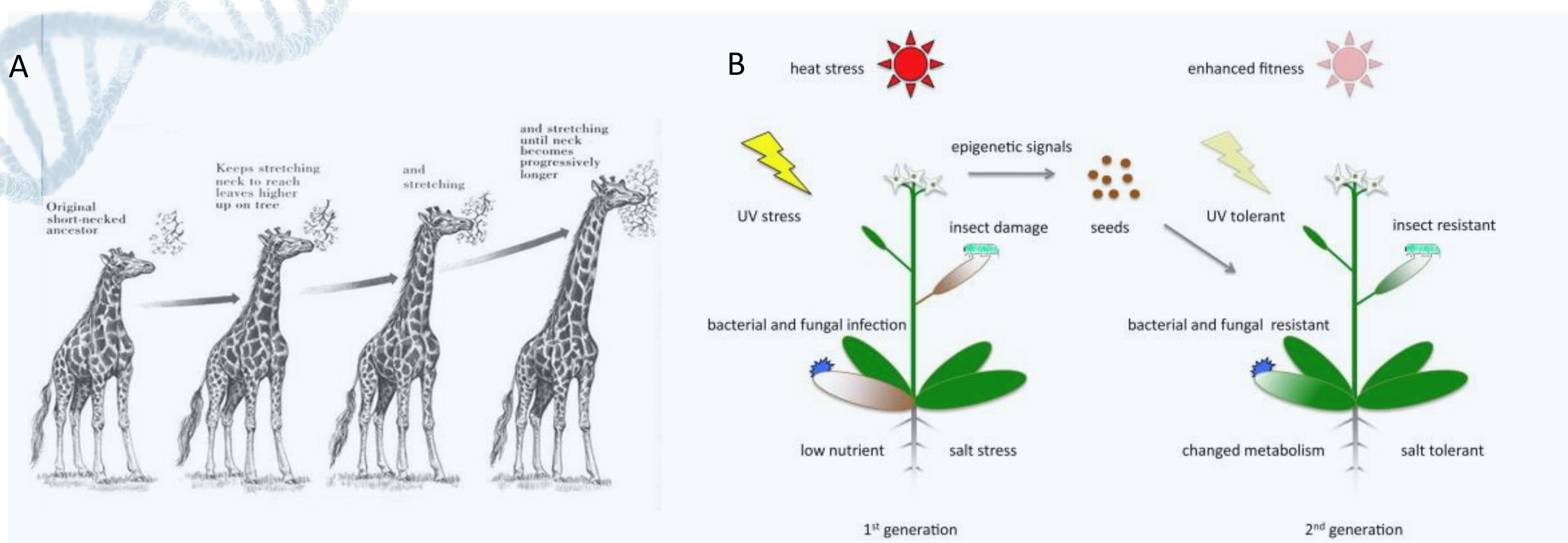

Fig. 2. Illustration of *transgenerational epigenetic inheritance* influenced by Lamarck's theory ('acquired traits could be passed onto offspring') (Fig. 2A). In Figure 2B, survivors (1st generation) create memory by utilizing epigenetic signals and the resistance trait could be passed through generations. Fig. 2A created by Theogoth (2014), Fig. 2B created by Ito (2014).

Conclusions

Epigenetic plant stress memory is controlled in a highly regulated manner. Because not all memories are passed down, the Lamarck theory of evolution does not describe how acquired traits could be passed onto offspring in general terms. However, by his influences (theory) on epigenetic regulation of plant stress memory, now scientists are able to create plants with the same phenotypes and are thus favorable for agricultural industry to improve human welfare.

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