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Effect of flooding stress on cocoa (*Theobroma cacao* L.)

Efecto del estrés por inundaciones en cacao (*Theobroma cacao* L.)

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Abstract

Despite the fact that cocoa is very important for small farmers, information about flooding stress is scarce and dispersed being a serious problem. Flood affects cocoa trees in different levels. For example, this kind of stress disrupt the physiology in term of photosynthesis and stomatal conductance; likewise, it provokes damages in the photosystem II reason for which plants of cocoa under flood display high value of Fv/Fm. On the other hand, the overabundance of water reduces the capacity plant have to take nutrients (macro and micro nutrients) from soil. The Reduction of growth and the yield are other symptoms that cocoa trees may be under anoxic conditions. It was interesting to find that cocoa has biochemical strategy to overcome lack of oxygen such as increasing the glycolysis. This specie also has morphological strategy such as forming lenticels. It is very important to choose a flooding stress tolerant cultivar to limit the negative effects of this abiotic stress.

Resumen

El estrés por inundación en cacao es un problema cuya información está dispersa y es escasa, a pesar de que este cultivo es importante para los pequeños agricultores. Las inundaciones afectan a los árboles de cacao en diferentes niveles. Por ejemplo, este tipo de estrés altera la fisiología en términos de fotosíntesis y conductancia estomática; asimismo, provoca daños en el fotosistema II por lo que las plantas de cacao bajo inundación presentan valores elevados de Fv/Fm. Por otro lado, el exceso de agua reduce la capacidad que tienen las plantas de tomar nutrientes (macro y micronutrientes) del suelo. La reducción del crecimiento y el rendimiento son otros síntomas de que los árboles de cacao pueden estar en condiciones anóxicas. Fue interesante encontrar que el cacao tiene una estrategia bioquímica para superar la falta de oxígeno, como aumentar la glucólisis. También tiene una estrategia morfológica como formar lenticelas. Es muy importante elegir un cultivar tolerante al estrés por inundación para limitar los efectos negativos de estrés abiótico.

Introduction

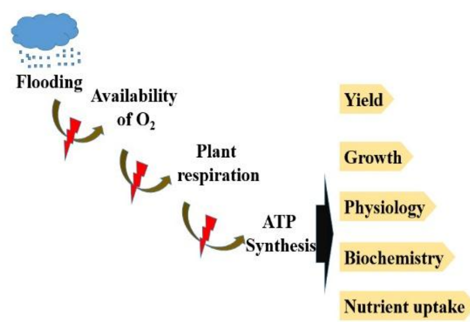
The cocoa production is the main livelihood of 5-6 million of smallholders distributed in developing countries as Ivory Coast, Ghana, Indonesia, Nigeria, Cameroon, Brazil, Ecuador and Peru[1,2]. Within those countries, the cocoa production is located in forestland where it has an important ecological role maintaining the biodiversity of insects and plants, and increasing the carbon sequestration[3-6]. Likewise, cocoa production has key social role since it generates employment. For example, in Peru, around of 190 thousand families and 450 thousand people both depend on cocoa crop[7] (Figure 1).

Figure 1 Wild Cocoa tree planted in Lima, Peru

It is indubitable that crop productivity is associated to climatic conditions, hence any modification in this can disturb the development and growth of the cocoa trees. Therefore, there are two phenomena associated to climate change: drought and flooding. Although, the damage caused by water deficit is more intense than water excessive[8], however, the waterlogging can disrupt the good performance of photosynthesis[9] and it decreases the yield of crops[10]. For that reason, it can be considered a threat to the food security[11].

In the last years, the global climate has come changing dramatically, increasing among other parameters, the presence of heavy rain in short periods[12] putting the production of certain crops at risk, especially those grown on forestland or near to river bank as cocoa (*Theobroma cacao* L.). This is due to the fact that overabundance of water on soil decreases dramatically the presence of available O_2 (anoxic) to roots provoking physiological, morphological and biochemical changes of the cocoa plant, causing decreased yields[13,14] (Figure 2).

Figure 2 Effect of flooding in plant development. Prolonged periods of rain may provoke flooding that, at the same time, decreases the availability of O_2 to plants. In these circumstances the respiration is disrupted, and consequently the ATP synthesis. All those changes can negatively affect the physiology, nutrient uptake, growth and yield of crops, particularly cocoa



In order to face this abiotic problem, we need to know the impact of flooding on different aspects that determine the adequate growth and yield in cocoa trees. In spite of the waterlogging stress can potentially increase its negative impact on cocoa plantations, information on the issue is scarce. Additionally, the material relates to this stress is dispersed. In this context, this review aims to group and classify all information of the impact of flooding on the cocoa plant.

Development

Effect on physiology of cocoa. Photosynthesis is one of the most important physiological processes in plants[15] being responsible for synthetizing carbohydrates, that will be used to maintain the growth and development of crops[16]. To carry out this vital process the plants count on a photosynthetic apparatus that transforms the sunlight in energy.

That process is highly dependent on the entry of CO_2[17]. Therefore, whatever that disrupt the entry of CO_2 into plants can impair the photosynthates production. This relationship also denotes the high impact of abiotic factors, such as flood, on photosynthesis.

When the soil is totally covered by water, cocoa physiology in terms of photosynthesis and stomatal conductance[9,18] are affected. In fact, the former can be reduced by 60-83 %[13,19], meanwhile, the latter can reduce by 81 %[13]. Furthermore, the transpiration is reduced by almost 60 %. The reduction in both photosynthesis rate and stomatal conductance could be associated to stomatal closure[20] that, at the same time, could be correlated to hormones such as ethylene[21].

On the other hand, the photosynthetic apparatus is formed by Photosystems (FS) (I and II) whose functions are to catalyse the transfer the electrons from plastocyanin to ferrodoxin (FS I) and to oxidize water (FS II)[22,23]. One of the methods to measure impact of abiotic stress on PS II is quantifying the fluorescence[24]. Interestedly, although some researchers as Bertolde et al.[13] documented that Fv/Fm can be negatively affected by excess water in the soil, other such as Costa et al.[25] showed that photosynthetic efficiency (Fv/Fm) was almost constant in plant under flood stress, but the same plants rapidly modified the total performance index (PI_{tot}), suggesting the latter may be better parameter to evaluate the impact of waterlogging on plant vitality[26]. According to Živčák et al.[27] and Swoczyna et al.[28], PI_{tot} is related to quantum efficiency to reduce the PSI with photons from FSII. Regarding PSII fluorescence, da Silva Branco et al.[29] informed that flooding stress decreases q_p as tolerant cultivar as resistant cultivar. Nevertheless, cocoa plants under anoxic conditions can slightly raise the water use efficiency (WUE)[30].

Effect on biochemistry of cocoa. The activity of different protective enzymes allow plant to survive adverse conditions. The enzymatic response depends on the genotype as evidenced by Bertolde et al.[13] in an experiment in which they observed that tolerant and susceptible genotypes to flooding showed differentiated enzymatic activity (Peroxidase and Polyphenol oxidases) compared to Control. The plant response also depends on time of exposure.

Furthermore, the content of starch and soluble sugars, in general, was reduced in the roots of plants subjected to waterlogging[13], pointing out the high susceptibility of this organ to excessive water. In addition, proline might be an indicator of stress due to excessive water, but only for short term response, although it depends on cultivar studied[8].

In this review, we found low information about the relation between anoxic (waterlogging) and respiration. However, the data found demonstrate that in flood-tolerant genotypes of cacao (TSA-792), the activity of alcohol dehydrogenase (EC 1.1.1.1), pyruvate carboxylase (EC 6.4.1.1) and lactate dehydrogenase increases, suggesting that an increment of glycolysis may be proper strategy used by tolerant genotypes[13]. This strategy is mentioned by other author s such as[31] who also reported that glycolysis helps plants to produce rapidly ATP.

Effect on nutrient uptake. The plant nutrients are many important because ones prompt the growth and development of plants, Therefore, a deficiency in their content can affect the yield of plant as cocoa. The levels of nutrient in plants are severely affected by the excessive water on soil. Macronutrient such as N, P, K, Ca and Mg were negatively affected by overabundance of water on soil[13,32]. In the case of micronutrients (Fe, Zn, Cu and Mn), the cocoa plants (both tolerant and susceptible to waterlogging) under flood stress had low absorption of these elements.

Effect on growth and morphology of cocoa. Inhibition of plant growth caused by waterlogging is reported in many crops, such as tomato[33] and oilseed rape[34]. In the case of cocoa, the suppression of vegetative growth by flood stress is pointed out by de Almeida & Valle[14] who stated that these phenomena limit the initial growth of cocoa seedlings diminishing the leave area and provoking the falling of leaves. Likewise, in an experiment with a four months old seedling subjected to waterlogging by one month, the researchers noticed some symptoms of hypoxic such as chlorosis in mature leaves, decreased leave formation, and reduced of root carbohydrates[13,32].

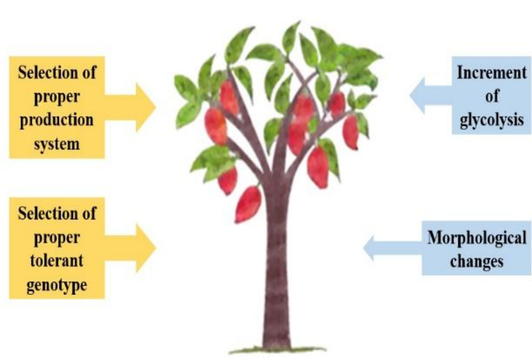
The reduction of growth is probably related to reduction of dry matter as informed by Prawoto et al.[35], who determined that soil water content 25 % above of field capacity (FC) decreased the dry matter by 13 %, likewise, when the soil water content was 75 % above FC the reduction of dry matter was 34 %. These results are according to other ones informed by de Almeida & Valle[14] and Rehem et al.[32]. Other traits studied in cocoa cultivars were the relative growth rate (RGR) of leaves and roots which decreased when the plants grew under excessive water[18,32]. However, the specific leaf area (SLA) increased in the same experiment[32].

A probably mechanism to overcome the hypoxic caused by waterlogging is the increment of lenticel on the trunk of cocoa tress as reported by de Almeida et al.[19], Rehem et al.[32] and Bertolde et al.[36]. In this sense, other researchers found overabundance of soil water stimulated the production of hypertrophied lenticels and adventitious roots in *Quercus robur* and *Quercus petraea*[37]. Other morphological strategy is the formation of adventitious roots[36]. Furthermore, adaptations of cocoa plants under waterlogging are the reduction of xylem, phloem and mesophyll length[38].

Effect on production of cocoa. In spite of there is a lot of information about the effect of waterlogging in different crops, in the case of cocoa this type of information is still scarce. According to de Almeida & Valle[14] the anoxia can reduce the productivity until 60 %.

Strategic adaptation to waterlogging. In order to deal with excessive water on soil, we need to start choosing a vegetative material suitable which be tolerant to flood stress (for instance TSA-792, CP-49)[32,39]. We must also select a proper production system as agroforestry system (AF). In fact, in an AF the number of survived cocoa plants was higher than cocoa trees unshaded, both growing under flooding[40]. Other strategies recorded were the increment of the glycolysis and morphological modifications (e. g. increase of lenticels)[36,38] (Figure 3).

Figure 3 Strategies to cope with waterlogging for cocoa plantations. To limit the impact of flood on cocoa trees first we have to choose proper production system (for example, agroforestry system). Second, we need to use tolerant cultivar. Internal and external processes such as glycolysis and morphological changes can help cocoa tress to overcome flooding stress



Future perspectives

Finally, after searching for information related to the effect of waterlogging on cocoa plants, it has been shown that excess water in the soil (anoxic) can negatively affect the physiology (e. g. reducing net assimilation and stomatal opening), enzymatic activity of peroxidases and polyphenol oxidases, absorption of nutrients (macro and micro nutrients) and the growth of cocoa plants. However, this specie has certain mechanisms to counteract the damage of the lack of oxygen in the root zone, such as the increase of glycolysis. As well, this specie forms lenticels when it is under anoxia. Different agronomic practices can be important to counteract the effect of flood; for example, we have to choose appropriate system of production (in this case agroforestry) and to cultivate flooding tolerant genetic material. In spite of information exists about this issue, it is necessary more research in order to understand better what mechanisms cocoa plants have to survive, or overcome the anoxic condition.

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Conflicts of interest

The authors state there is no conflicts of interest.

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Ethical considerations

The authors declare there is no plagiarism in this manuscript.

Authors' contributions

Saravia-Castillo Gabriela, *Castro-Cepero Viviana*, *Julca Otiniano Alberto*, *Alvarado-Huamán Leonel*, *Borjas-Ventura Ricardo*, searched, organized and analyzed the information and reviewed the final version of this document.

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