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Effect of Climate change on Crop Genetic Diversity and Productivity

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Abstract

Climate change is a major environmental challenge to the world with significant treats of ecosystems, food security, water resources and economic stability. Climate change has the potential to irreversibly damage the natural resource base on which agriculture depends and in general adversely affects agricultural productivity. The sustainability of crop production and food security is being threatened by the increasing unpredictability and severity of drought stress due to global climate changes. Incorporation of these adapted natural genetic variations into breeding programs can enrich the current genetic diversity of stress tolerance and improve yield under stress. Food Security exists when all people, at all times, have physical and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life. Climate change affects food security in various ways: through impacting on all four components of food security (availability, accessibility, affordability, utilization and nutritional value and food system stability), through impacting on crop production and yield, through impacting on water availability, through impacting on fisheries production, through impacting on agricultural pests (weed, insect and disease pests), and through impacting on livestock production. Climate change is threatening crop productivity worldwide and new solutions to adapt crops to these environmental changes are urgently needed. Elevated temperatures driven by climate change affect developmental and physiological plant processes that, ultimately, impact on crop yield and quality. Generally, Climate change is threatening crop productivity worldwide and new solutions to adapt crops to these environmental changes are urgently needed. Elevated temperatures driven by climate change affect developmental and physiological plant processes that, ultimately, impact on crop yield and quality. Plant breeding is the activity of developing diverse plant varieties that can contribute usefully to cropping and production systems.

Keywords: Climate Change; Food Security; Genetic Diversity, Crop Productivity

1. Introduction

Climate refers to the long-term regional or even global average of temperature, humidity and rainfall patterns over seasons, years or decades whereas weather refers to atmospheric conditions that occur locally over short periods of time from minutes to hours or days. Climate change is the global phenomenon of climate transformation characterized by the changes in the usual climate of the planet (regarding temperature, precipitation, and wind) that are especially caused by human activities (Bernhard, G.H *et al*., 2020). As a result of unbalancing the weather of Earth, the sustainability of the planet's ecosystems is under threat, as well as the future of humankind and the estability of the global economy. Climate refers to a long-term variation in the atmospheric condition of a specific region whereas climate change is a gradual change in the climate system both by natural and artificial causes. Climate change is caused by the change in each component of the climate system such as atmosphere, hydrosphere, biosphere, cry sphere and lithosphere or by complicated interactions among those components (Gornall *et al*., 2010).

The causes of climate change are largely divided into natural causes and artificial causes. Natural causes include the change in solar activity, volcanic eruption, sea water temperature, ice cap distribution, westerly waves and atmospheric waves whereas artificial causes include carbon dioxide emission from industry and agricultural production activities, deforestation, acid rain and the destruction of the ozone layer by Freon gas, global warming by the increase of greenhouse gases (Ranaivoson A *et al.*, 2012). Global warming refers to the average increase of the Earth's temperature due to the greenhouse effect caused by carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydro fluorocarbon (HFCs), per fluorocarbon (PFCs) and sulfur hexafluoride (SF6). Global warming is a continuous increase of the Earth's temperature due to the greenhouse effect, started from the time of the Industrial Revolution which was accompanied by a rapid increase of fossil fuel consumption. This issue has attracted international interests as the scientific knowledge of climate has accumulated since the 1970s and it has been widely accepted by scientists that the anthropogenic greenhouse gas emissions are the cause of global warming. The global greenhouse gas concentration based on carbon dioxide is estimated to have increased from 280ppm before the Industrial Revolution (1750) to 379ppm in 2005.

According to an analysis of the average temperatures of the Earth, the Earth's average temperature is increased since Industrial Revolution as compared to pre- industrial revolution (Hasselmann, K., 2010). Specifically, global warming has significantly accelerated since 1980 and the average temperature of 1998 was shown to be 0.58 higher than the average temperatures of 1960~1990. Climate change by global warming refers to the average increase in global temperature and has become a megatrend that will lead to significant global changes in the future. Recent climatic models predict that the 21th century will be characterized by increasing temperature, changing precipitation patterns and more frequent severe events such as heat waves and droughts (Pourbabaei *et al*., 2014). Climate change is one of the most important ecological problems of our times (Eppich *et al*., 2009). Agricultural production systems are facing challenges posed by climate change, water scarcity, increasing population and economic fluctuations, particularly in semi-arid regions (Eigenbrode, S.D *et al*., 2018). The variability of water and temperature regimes definitely affects yield stability, resulting in global food insecurity (Wang, J *et al*., 2018). Soil tillage and water management as well as stress-tolerant cultivars have been promoted as potentially important measures for adaptation to climate change (Pittelkow, C.M *et al*., 2014).

Climate change is contributing to the loss of biodiversity, but the crop diversity that is expected to play a significant role both in mitigating and adapting to adverse effects climate change. A key to achieving adaptation is broadening the genetic base of crops. Crop genetic diversity enables farmers and plant breeders to develop higher yielding, more productive varieties that have the improved quality characteristics required by farmers and desired by consumers. Genetic diversity has significant role in ensuring food security through increasing farmer's income and plays in current and future food production (Bhandari HR *et al*., 2017). Growing different crops and different varieties of the same crop is fundamental for the livelihood of millions of small-farmers around the world in providing both diversified diets and household food consumption in the face of uncertain ecological and socio-economic conditions. Genetic diversity has paramount role in the perpetuation of a species through offering adaptation mechanisms to biotic and a biotic environmental stresses and enables change in the genetic composition to cope with changes in the environment (FAO, 2012). Plant genetic diversity is playing a key role in the continuation of agricultural development with significant improvement in different morphological and agronomical characteristics.

Developments of resistance crops against different stresses are primarily relied on the variation exist in the genetic diversity of cultivated and their wild relatives together for further improvements. Genetic diversity is the extent of genetic variation available among crop species to use in improvement program. The presence of sufficient genetic variation is a key for the success of the development resistance cultivars against climate changes. Genetic diversity determines the efficiency and effectiveness of improvement which may result in enhanced food production. The achievement in the crop improvement primarily relies on the broad base of degree genetic divergence (Mohammadi SA and Prasanna BM, 2003). In ensuring food and nutritional security, genetic diversity is contributing very amble quantity.

Knowledge of genetic diversity of the genetic material is very critical in crop improvement. Effective selection is highly important in any crop improvement where the sufficient genetic variation is available for different characters. Crop improvement is very crucial to satisfy the world demand in the presence of different challenges like climate change, reducing arable land and increasing population growth.

Climate change and variability are the real threats to agriculture and food security (Rezaei EE *et al*., 2015). Extreme weather events and uncertainty in rainfall patterns are negatively affecting the agricultural crops (Ahmed I *et al*., 2018). Crop genetic diversity required worldwide particular attention of scientists and policy makers since its importance is very paramount in ensuring food and nutritional security. Crop genetic diversity has tremendous role in mitigating the impact of climate change and devising adaptation strategies of crop diversity to the severe climate change is not the only important to offer basic demand to human being but also plays a major role in ensuring its quality. The fight to achieve food security and end hunger is one of the greatest challenges facing the world. Rising populations, diminishing resources and deteriorating environments only raise the stakes. A greater diversity of genetic resources in gene banks, available to all through an efficient, global ex situ conservation system, helps to ensure a secure food supply at more stable prices. It provides the raw genetic material to breed for a more nutritious and varied food supply and increases the access of the poor to more affordable and healthier food to fight malnutrition. The objective of the paper was to understand and aware the most appropriate adaptation and mitigation measures to climate change impacts on the agricultural production and productivity grown under the semi-arid conditions.

2. Adapting to Climate Change

Climate change adaptation is the action to global warming which helps to reduce the vulnerabilities in the social and biological system. The main objective of adaptation strategy is to build the resilient in societies against climate change (Smit B and Wandel J, 2006). Agriculture sector is highly vulnerable to changing climate. Extreme weather conditions and changing patterns of precipitation affects the crop development, growth and yield of crops. High temperature at critical growth stages could reduce the grain filling duration caused the grains sterility and consequently yields reduction (Ahmed I *et al*., 2018).

To avoid the risks in agriculture associated with climate change, adaptation is the key factor that could help to mitigate the negative of climate change. Adaptation strategies provide an opportunity to address the climate change challenges and to sustain the crop production (Fischer G, *et al*., 2002). The development of improved varieties such as early maturing, drought and heat tolerant are necessary to sustain the productivity under changing climate. The new cultivars would increase the production per unit area under moisture stress and extreme temperatures (Deressa TT *et al*., 2009).

Climate change is a serious threat to agriculture and food security. Extreme weather conditions and changing patterns of precipitation lead to a decrease in the crop productivity. High temperatures and uncertain rainfall decrease the grain yield of crops by reducing the length of growing period. Future projections show that temperature would be increased by 2.5°C up to 2050. The projected rise in temperature would cause the high frequent and prolong heat waves that can decline the crop production. The rise in temperature results in huge reduction in yield of agronomic crops. Sustaining the crop production under changing climate is a key challenge. Therefore, adaptation measures are required to reduce the climate vulnerabilities. The adverse effect of climate change can be mitigated by developing heat tolerant cultivars and some modification in current production technologies. The development of adaptation strategies in context of changing climate provides the useful information for the stakeholders such as researchers, academia, and farmers in mitigating the negative effects of climate change.

Table 1: Climate change adaptations for agronomic crops

Crop (s) name	Adaptation	References
Wheat	Use of heat tolerant cultivars Adjustment of planting dates Optimum plant population	Ahmad I, *et al*. (2018)
Rice	System of rice intensification with alternate wetting and draying Direct planting	Weerakoon WMW *et al*. (2011)
Maize	Raised bed planting Early maturing cultivars Precision nutrient management	CIAT *et al*. (2017)
Cotton	Heat and drought tolerant cultivars Increase in plant population by 18%	Rahman MH *et al*. (2018)
Sugarcane	Ratoon management Pit planting	Singh J *et al*. (2011)
Chickpea	Integrated weed control Agro-forestry (Wind barrier) Improved crop varieties (early maturity)	Ratnam M *et al*. (2011)

2.1 Effects of Green-House Gases

The main driver of climate change is the greenhouse effect. Some gases in the Earth's atmosphere act a bit like the glass in a greenhouse, trapping the sun's heat and stopping it from leaking back into space and causing global warming. Many of these greenhouse gases occur naturally, but human activity is increasing the concentrations of some of them in the atmosphere in particular: carbon dioxide (CO_2), methane, nitrous oxide and fluorinated gases. CO_2 produced by human activities is the largest contributor to global warming. By 2020, its concentration in the atmosphere had risen to 48% above its pre-industrial level (before 1750). Other greenhouse gases are emitted by human activity in smaller quantities. Methane is a more powerful greenhouse gas than CO_2, but has a shorter atmospheric lifetime. Nitrous oxide like CO_2 is a long-lived greenhouse gas that accumulates in the atmosphere over decades to centuries.

Natural causes, such as changes in solar radiation or volcanic activity are estimated to have contributed less than plus or minus 0.1°C to total warming between 1890 and 2010. Climate change is a long-term challenge, but requires urgent action given the pace and the scale by which greenhouse gases are accumulating in the atmosphere and the risk of more than 2°C global temperature rise. Greenhouse gases driving climate change, affect directly crop productivity (IPCC, 2014). Higher concentrations of CO_2 are expected to act as a fertilizer by improving net photosynthesis rates and increasing water use efficiency (Deryng *et al*., 2016). This positive effect is higher in C_3 plants such as wheat, rice and soybean due to the limited photosynthetic output of photorespiratory carbon losses. Nevertheless, in the long term, the constant increment of CO_2 concentration will have a negative impact in the climate, thus counterbalancing the increase in crop yield (Senapati *et al*., 2019). On the other hand, O_3 changes have significant negative effects on the yield of major agricultural crops. O_3 is one of the most highly reactive oxidants, provoking damage in plant tissues, which includes visible leaf injuries, decreased photosynthesis and accelerated senescence and cell death (Vandermeiren *et al*., 2009). But interestingly, there are pronounced differences in O_3 sensitivity between species (Mills *et al*., 2007). Ozone (O_3) causes a decrease in crop biomass in wheat and soybean, more specifically root biomass, during reproductive and grain filling stages leading to a reduction of overall crop yield. Consequently, global production losses due to O_3 in these crops are expected to be higher than losses in rice and maize (Feng Z. *et al*., 2019; Wang Y. *et al*., 2019).

Climate change is causing the shifting of the rainfall patterns. More intense rainfall producing flooding periods, the appearance of drought seasons and offseason precipitations are expected. In several prediction models, offseason rainfall during critical stages of crop growing could lead to a very significant reduction in crop yield (Lobell and Burke, 2008). In winter oilseed rape, it has been reported that a more intense rainfall during autumn and winter periods may boost the appearance of diseases (Sharif *et al*., 2017) and in maize and soybean, more intense precipitations in spring provoke early damage in young plants (Sharif *et al*., 2017). Another risk associated to more extreme rainfall is the intensification of flooding events. Floods put in danger the food security of these countries by destroying cropping areas or delaying crop planting due to high soil moisture (Xu *et al*., 2013). Seawater flooding of coastal regions is becoming more frequent because waves and storm surges are getting stronger (Vitousek *et al*., 2017). Osmotic and anionic stress caused by the high salinity of seawater will become an additional problem to crops besides the low O_2 and CO_2 levels caused by anoxia.

More frequent drought events are also expected due to longer periods without rain added to warmer temperatures. Although droughts restrict cropping areas, the decrease of agricultural productivity is mainly caused by a severe direct effect on crop yield (Zipper *et al.*, 2016). The most damaging impact of drought stress on crop productivity occurs at reproductive or growing stages. In general, a drought period causes a reduction of water consumption by the plant, leading to a stomata closure and lower CO_2 intake. Following decrease in photosynthesis ratio provokes a final reduction of crop biomass (Garofalo *et al*., 2019). The water scarcity imposed by drought is frequently accompanied by salinity stress. The ion toxicity and the reduction of soil water potential contribute to a severe reduction of plant growth. Soil salinity reduces yield in highly tolerant crops as cotton, barley and sugar beet as well as in crops with high salinity sensitivity as sweet potato, wheat or maize (Zorb *et al*., 2019).

All these adverse climate effects together with elevated temperature will increase agriculture losses even further (Tai and Val Martin, 2017). Numerous studies suggested that global warming will lead to substantial declines in mean crop yields in the next future and that the most serious agricultural impacts will occur in the tropics, where the majority of the world's food-insecure population resides (Battisti and Naylor, 2009). Furthermore, mean crop yield will decline and their variability will increase even if interannual climate variability remains unchanged (Tigchelaar *et al*., 2018). Adding up these and other effects, models show possible yield losses of 6–10% per 1°C of warming in the average temperature of the growing season (Guarino and Lobell, 2011). Moreover, climate variation is already causing a major effect on the stability of crop production. Yields of the top ten global crops like barley, cassava, maize, oil palm, rapeseed, rice, sorghum, soybean, sugarcane and wheat has been affected significantly in different regions all over the world (Ray *et al*., 2019).

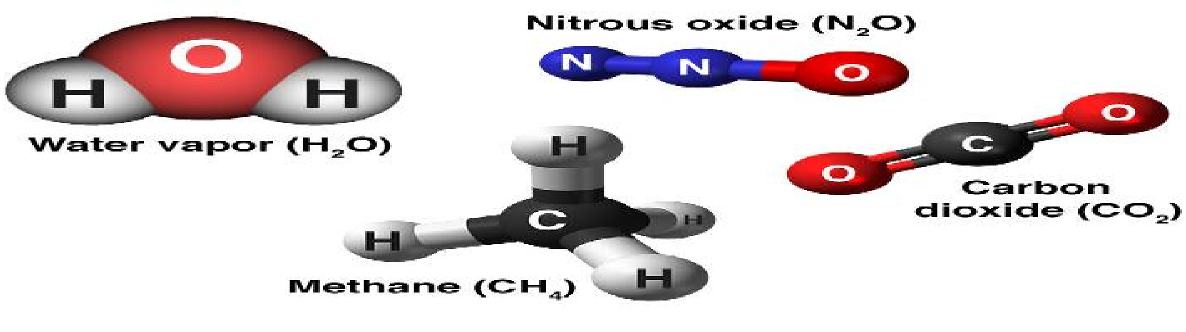

Figure 1: Greenhouse gases contributing world global warming

2.2 Food and Climate Change

Climate change is projected to reduce yield growth rates in much of the world, especially in tropical regions. The Intergovernmental Panel on Climate Change reported that climate change might reduce yields per hectar of wheat, rice, and maize by up to 2 percent per decade starting 2030 compared with projected yields without climate change (Ray *et al*., 2013). The Earth's climate continues to warm and all the model simulations predict a global trend to warmer temperatures (Lean and Rind, 2009). The global population is expected to reach nine billion by 2050, representing an additional two billion people to feed (Ray *et al*., 2013). The projections show that feeding world's population would require raising the overall food production by around 70% by 2050 (FAO, 2009a).

However, current trajectory shows that the rates of global production in key crops would increase far below what is needed to produce enough food to meet the raising population demands (Ray *et al*., 2013). This widening mismatch between demand and supply is causing concern for future food security (*Godfray et al*., 2010). Further reasons for alarm are the yield losses predicted to be provoked by climate change (Tai *et al*., 2014). Although climate changes will not impact crop production evenly according to geographical distribution, it will threaten food production globally (Thiault *et al*., 2019). For all those reasons, there is an urgent need to maintain and improve crop productivity under these climatic constrains. Global food security would be endangered resulting in the increase of food prices and food shortages and in consequence increasing global hunger, poverty and inequality. So, it is of paramount importance the improvement of crop tolerance to abiotic and biotic stresses in order to confront climate change effects.

Climate change affects crop production through direct impacts on the biophysical factors such as plant growth and the physical infrastructure associated with food processing and distribution (Schmidhuber and Tubiello, 2007). With increasing frequency of droughts and floods associated with climate change, agricultural production will decline and the state of food insecurity and malnutrition will increase (Schmidhuber and Tubiello, 2007). It is estimated that African farmers are losing about US$28 per hectare per year for each 1°C rise in global temperature.

Table 2 : Summarizes their findings for median production losses in key African staple crops across the continent by 2050

Types of crop	Average % production loss predicted by 2050
Maize	22 %
Sorghum	17%
Millet	17 %
Groundnut	18 %
Cassava	8 %

Source: ((FAO, 2010)

2.3 Impact of Climate Change on Food Security

According the United Nations' Committee on World Food Security, food security is defined as meaning that all people at all times, have physical, social and economic access to sufficient, safe and nutritious food that meets their food preferences and dietary needs for an active and healthy life (FAO, 1996). Food insecurity is a measure of the unavailability of food and individuals' ability to access it. Food security depends on availability of food, access to food, and utilization of food (FAO, 2000). The common definition of food security rests on three pillars: food availability, food access, food utilization and their stability (Ericksen *et al.*, 2011). Indicators used to measure food availability include crop production and food production indices, livestock ownership indices and national food balance sheets (Renzaho and Mellor, 2010). Access to food is the set of alternative commodity bundles that a person can command in society by using the totality of rights and opportunities that he or she faces (Sen, 1984).

Food accessibility is a measure of the ability to secure entitlements, which are defined as the set of resources (including legal, political, economic and social) that an individual requires access food. Food utilization is utilization of food through adequate diet, clean water, sanitation and healthcare to reach a state of nutritional well-being where all physiological needs are met. Food utilization is “the nutritional value of the diet, including its composition and methods of preparation; the social values of foods, which dictate what kinds of food should be served and eaten at different times of the year and on different occasions; and the quality and safety of the food supply, which can cause loss of nutrients in the food and the spread of food borne diseases if not of a sufficient standard (FAO (2008a). Food stability is all about a population, household or individual must have access to adequate food at all times. The concept of stability therefore refers to the availability, access and utilization dimensions of food security. All dimensions of food security are thus closely intertwined with agriculture production which is both source of food and source of income for rural households. Food security vulnerability to climate change refers to the propensity of the food system to be unable to deliver food security outcomes under climate change and food security vulnerabilities to climate change encompass the environmental, economic and social dimensions (FAO, 2016).

As a result of the cascading impacts and specific vulnerabilities to food security description, climate change impacts four dimensions of food security like availability, access, utilization and stability directly and indirectly (FAO 2011). All dimensions of food security are affected by climate change and food security depends not only on the direct impact of climate change on food production, but also on human development, economic growth, trade flows, and food aid policy (Keane *et al*., 2009). Climate change has major implications on food security and livelihoods (Thompson and Scoones, 2009). Climate change affects food security, water availability and productivity levels in Africa (Hope, 2009). Climate change is expected to affect all of the components that influence food security: availability, access, stability and utilization.

Components of Food Security

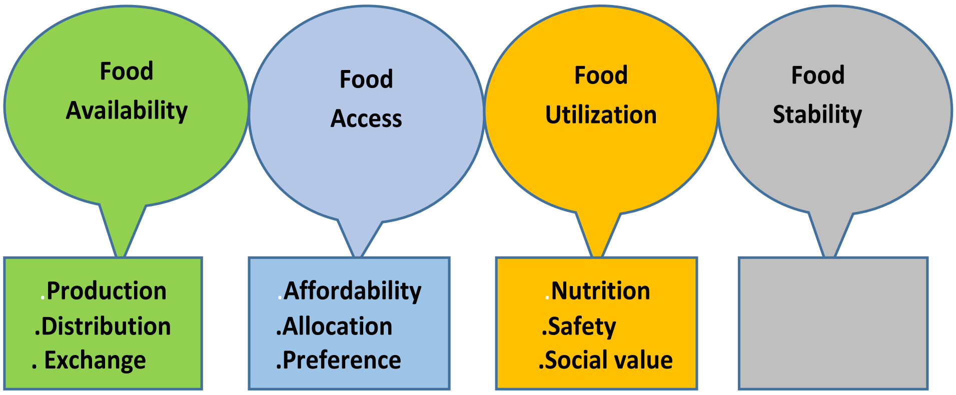

Figure 2: Basic Components of Food Security

3. Conclusion

Climate change refers to changes beyond the average atmospheric condition that are caused both by natural factors such as the orbit of earth’s revolution, volcanic activities and crustal movements and by artificial factors such as the increase in the concentration of greenhouse gases and aerosol. Global warming refers to the rise in global temperatures due mainly to the increasing concentrations of greenhouse gases in the atmosphere. Climate change refers to the increasing changes in the measures of climate over a long period of time including precipitation, temperature and wind patterns. Global warming refers only to the Earth’s rising surface temperature, while climate change includes warming and the side effects of warming like melting glaciers, heavier rainstorms or more frequent drought. Climate change and variability have negative effects on crop productivity. Change in precipitation pattern, increase in frequency, and intensity of extreme events such as heat waves and drought have detrimental effects on grain yield.

Agriculture and climate change are internally correlated with each other in various aspects. climate change is the main cause of biotic and a biotic stresses, which have adverse effects on the agriculture of a world. The land and its agriculture are being affected by climate changes in different ways, example, variations in annual rainfall, average temperature, heat waves, modifications in weeds, pests or microbes, global change of atmospheric Co_2 or ozone level and fluctuations in sea level. The threat of varying global climate has greatly driven the attention of scientists, as these variations are imparting negative impact on global crop production and compromising food security worldwide. According to some predicted reports, agriculture is considered the most endangered activity adversely affected by climate changes. To date, food security and ecosystem resilience are the most concerning subjects worldwide. Climate-smart agriculture is the only way to lower the negative impact of climate variations on crop adaptation, before it might affect global crop production drastically.

The wise use of crop genetic diversity in developing improved crops can contribute significantly to protecting the environment. Drought-resistant plants can help save water by reducing the need for irrigation. Deeper rooting varieties can help stabilize soils and varieties that are more efficient in their use of nutrients require less fertilizer. Climate change will place unprecedented pressures on our ability to grow the food we require. These impacts will be particularly severe in developing countries. Scenarios from the Intergovernmental Panel on Climate Change show warming will take place over the next several decades irrespective of any action we take today. The same models show conditions for agriculture will be dramatically different from those which prevail today. Adapting agriculture to these future conditions is essential. Climate change scientists widely recognize the need for new and improved crop varieties that can withstand these challenges. These improved crops are essential not only to reduce hunger but also to strengthen global food security in the medium and long term. The development of crop varieties that can cope with heat, drought, flood and other weather extremes may well be the single most important step we can take to adapt to climate change. Most importantly productive agricultural systems reduce or eliminate the need to cut down forest or clear fragile lands to create more farmland for food production.

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