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Opinion

What Would It Take to Continue Feeding the World's Population? From Family Farming to a New, More Plural, Diverse and Technological Model of Producing Foods

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Abstract: The world population is continuously increasing. Increases in crop productivity are needed to fulfil food demands, although this approach is not the only solution to the problem. Yields below 2.4% of productivity increase per year would risk food security and lead to prices much higher than reasonable. Advances in potential yield and through yield gap closing are required. In addition, climate change threatens global food production and end-product quality. Setting aside extreme events, such as prolonged droughts or floods, the three main factors associated with climate change are increased temperatures, the rainfall reduction, and the increased atmospheric CO_2 concentration. All these three factors impact food production and its quality. Growers should adapt to this new scenario. The key to success in feeding the world's population in a changing climate will be to achieve a global farmer community with proper skills, an informed population and well-oriented research.

Keywords: climate change; crop breeding; crop yield and quality; food production; world's population

1. Feeding an Increasing World Population

World population is approaching currently 8263 million with an increase in the year 2024 of 95 million. Readers can monitor life world population at the following link https://countrymeters.info/en/World#Population_clock (accessed on 11 February 2025). At this rate of increase, it can be forecasted to reach almost 10 billion people in 2050 [1]. Some authors, notwithstanding uncertainties, have concluded that crop productivity increases of 1.1% per year is needing to feed the world's population in the mid-21st century [2]. This would imply an increase of crop production of 29% from now to 2050. In this context, it is worth noting that other authors point out that crop production must increase by 70% or double by 2050 to meet the food demands of the world population [3,4]. However, the average rate of increase is currently only 1.3%, with stagnant yields on up to 40% of the land under cereal production [5]. For all of these reasons, the ideal target for yield increases should be set to around 2.4% per year [6]. Yields below those would risk food security and lead to prices much higher than the reasonable ones of the years around 2010. However, a security margin would be desirable. Unanticipated shocks such as price spikes are likely to impact people of low socioeconomic status. Obviously, a higher target of yield increases would optimize the offer, minimizing the negative effects of an excess of demand. Another important aspect that should not be forgotten is food quality. Food provides all the essential nutrients to maintain human health. Also, and alongside the increase in population, changes in the diet, particularly due to the higher meat consumption in some developing countries, may exacerbate the demand for feed crops [2].

Across major crops feeding the world, the average rate of current yield increase is around 1.0–1.3% [2,4,5], with tendency to decrease. Nevertheless, far from one can think, this depressed tendency is not due to biological limits in the agro-system. In some cases, this has been caused by product quality considerations (rice in Japan), policies on input use (wheat in Western Europe), and surplus avoidance (wheat and rice in China). In other cases, this situation can be derived from regulations in pro of the environment, however it does not appear to be the seed for a global phenomenon [2].

Around one-half of the current yield increases occurring year after year is achieved through advances in potential yield. Potential yield can be achieved with the best adapted cultivar to the growing site, with the best crop management, and in the absence of both biotic and abiotic stresses. The remaining one-half occurs through yield gap (i.e., the difference between actual yield and potential yield) closing.

Crop breeding is expected to continue contributing to the increases in potential yield in the future. Conventional, traditional breeding continues delivering improvements in potential yields. With advancements in the modern biotechnology, genetic engineering included, has added indirectly improvements of yield, through for instance pest resistance. In addition, marker-assisted selection is a technique with great expectations to improve potential yields in the near future. On the other hand, yield gap closing hastening is a great opportunity for boosting crop yields. It should be highlighted that this approach uses existing technology and there is no need to develop or discover new technology. This is especially important for the developing countries from Asia and Africa, where the yield gap closing will benefit to the most economically disadvantaged people. Improving farmers skills is the way to make progress in this challenge, as discussed below.

There are different aspects that would help to advance on yield gap closing, which not all require extensive expenses. Investments in farmers training, establish more modern infrastructures, create institutions to organize farmers in cooperativities, and implement plans of research, development and innovation are key aspects to work with in the near future. For a real yield gap closing, efforts should be focused with special emphasis in developing countries. The resources should ideally come from both the public and the private sector. All these implementations will take time, in the meanwhile small targets and a step-by-step strategy must be adopted while waiting for an actual and global modernized crops agro-system.

Within the objective of feeding the future world, a multidisciplinary approach focused on the physiology and management of crops can be the success clue. Training of farmers in both developing and developed countries and investments in research, development and innovation will help to optimize resources and feeding the world's growing population. The key to success in this urgent challenge will be to achieve a global farmer community with proper skills, and an informed population, all based on data and outputs of a well-oriented research.

2. Climate Change Threatens Global Food Production and End-Product Quality

Climate change is one of the challenges current agriculture is facing now a days which will exacerbate in coming years. In addition to extreme climatic events that can cause prolonged drought episodes or flooding in many countries around the world, the three main factors associated with climate change are: (i) elevated day- and night-temperatures, (ii) the rainfall reduction resulting in low soil water availability, and (iii) the increased atmospheric CO_2 concentration. The Intergovernmental Panel on Climate Change (IPCC) has foreseen several scenarios that present different possible climatic shifts. The Representative Concentration Pathways (RCP) are climate change scenarios for projecting future concentrations of greenhouse gases. For instance, it has been reported that the global mean land and ocean surface temperatures have increased by 0.8 °C during the period 1888 to 2012 [7,8]. According to the worst scenarios, the global mean temperature expected for the end of the present century will be between 2.2 ± 0.5 °C and 3.7 ± 0.7 °C higher, RCP6.0 and RCP8.5 scenarios, respectively (IPCC, 2013) [9]. In addition, extreme heat events have been detected since 1950, and it is assumed that such extreme events are going to occur often in the future [8,10]. In fact, heat waves are projected to be more intense and longer-lasting, while cold episodes are projected to decrease significantly. Such changes are projected to occur almost everywhere [11].

Concomitantly to changes in temperature, increases in evapotranspiration and reductions in precipitation rates are expected, while a growing inequality in the distribution of precipitation around the world will make water reserves increasingly scarce [8,12]. Uncertainty is inherent in the Earth's water cycle. Projected geographical distribution of rainfall foresees increases in the north of Europe, a large part of Asia, north of North America, northwestern of South America and center of Africa, and decreases in the south of Europe, Australia, the rest of North America, north of Africa and north and east of South America [8] affecting, if confirmed, water availability in different parts of the world in different ways. Thus, precipitation regimes will change, affecting both the intensity and frequency of rainfall.

The monthly average CO_2 concentration at the Mauna Loa (Hawaii, USA) observatory reached in January 2025, 426.65 ppm, 3.85 ppm higher than the value of January 2024 (https://gml.noaa.gov/ccgg/trends/, accessed on 11 February 2025). If the rate of increase is maintained over time, an atmospheric CO_2 concentration of 715 ppm is very plausible at the end of the century. In the same way, the above-mentioned scenarios, RCP6.0 and RCP8.5, predict atmospheric CO_2 levels between 669.7 ppm and 935.9 ppm, respectively, for 2100 [9]. It seems that within these three factors related to climate change, the rise in atmospheric CO_2 is possibly the one more detrimental and difficult to face because elevated CO_2 will impact crops all over the world while the impacts of the increase in temperature and the decrease in water availability will be more localized or easier to counterbalance. Thus, while drought and elevated temperature can be potentially mitigated by, for instance, an increasing optimized irrigation, planting crops at higher altitudes within a given latitude, or displaced to cooler and wet latitudes within a country, the effect of elevated CO_2 is present at all latitudes and will act independently of where crops will be established. Hence, elevated CO_2-induced impacts would be much more challenging to mitigate.

These stress factors have important implications not only on crop physiology but also on the different management strategies growers should adopt to cope with losses in yields and impairments in quality. Elevated temperature was reported to accelerate crop development, reducing crop duration and lowering yields [13]. Schlenker and Roberts [14] concluded that under climate change scenarios with a temperature rise of less than 1 °C, crop productivity of maize and soybean will decrease by more than 50%. Adding to that, Hatfield and Prueger [15] reported that warmer temperatures mainly impacted the reproductive stage of maize development, and grain yield was significantly reduced by as much as 80−90% with respect to normal temperature regimes. Besides, increasing temperatures adversely affect plant growth and development, which could affect wheat productivity negatively. For each °C rise in temperature, wheat production is estimated to reduce by 6% [16]. Not only wheat, Zhao et al. [17] estimated that the temperature increase will reduce global yields of wheat, rice, maize and soybean in all major countries of production, USA, China, India, France and Russia. In addition to cereals, fruit crops will be also impacted. For instance, in grapevine, Kizildeniz et al. [18] in a three-year experiment reported a 50% reduction in yield in 2015 by a heat-wave when compared to yields obtained in 2014 and 2013. On the other hand, the available data shows that grain quality will be also affected. Heat stress will negatively affect grain starch concentration due to depleted starch biosynthesis metabolism and shortening of the grain-filling period, but it might increase total proteins and N concentration [19].

Water availability is another factor, possibly "the factor", that largely determines yield. During the past four decades, it is estimated that droughts caused losses of cereal production amounting to 1820 million kg globally [20]. In wheat crops, water deficits can diminish production by at least 60% [21]. Daryanto et al. [22] reported 40% and 60% yield losses in maize and bean, respectively, with ≈35% reduction in water; however, they indicated that the yield losses varied as a function of the phenological stage affected by drought. In general, for cereals (maize, wheat, and rice), the later phase of grain filling is more susceptible to drought than the vegetative stage [22,23]. With respect to water availability effects on quality, grain yield could be conditioned by the final starch concentration of affected plants. Adding to the increase in the Fe and Zn concentrations, Ben Mariem et al. [19] found that total protein concentrations are significantly increased, which is probably due to a dilution effect on starch and the accelerated reserve remobilization from source to sink to compensate for the nutrient uptake deficit that results from low soil water content.

Regarding CO_2, although the increase in atmospheric CO_2 might promote yield enhancement and starch accumulation through higher rates of photosynthesis, the grains of these plants will have lower concentrations of total proteins and minerals, leading to reduced baking quality and deficient nutritional value [19].

Overall, a trend towards yield reduction is being observed despite the existence of breeding programs aimed at developing new genotypes that are more efficient under limiting conditions, and this reflects the combined impact of all environmental factors on crop production worldwide. While the impacts of individual stress factors have been investigated during recent decades, the interactions between and among them have received comparatively much less attention [24]. In fact, when elevated CO_2 is studied as a single factor, crop production tends to increase, but under field conditions, various stress factors occur simultaneously, such as water scarcity and high temperature, which mitigate the positive effect of CO_2 on plant yields. Obviously, crop yields are constrained by the environment during the whole crop growth period. Therefore, climate models could be helpful tools to predict trends in crop productivity under future climate scenarios [25].

3. Discussion and Conclusions

Several studies highlight the fact that within the context of the present and near-future environments, it is crucial to increase crop yield through the development of stress resilient cultivars. While the current breeding programs and agricultural incentives are almost exclusively yield-based, breeding for improved cereal quality can meaningfully improve the nutritional value of agricultural end-products. For this purpose, a better understanding of how environmental growth conditions (such as elevated temperature, drought, CO_2, etc.) affect grain yield and nutritional parameters of cereals will help developing more nutrient-rich crops. Adding to that, exploring genetic diversity and variability of major crops is needed to discover genotypes more resilient to ongoing climate change.

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Conflicts of Interest

The author declares no conflict of interest.

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