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# Climate Change Implication on Cereal Crop Productivity

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**Key words:** Agriculture, Anthesis, Cereal, Climate change, Crop yield, Flowering, Pollen viability

**Abbreviations**: Black Carbon (BC), Carbon Exchange Rate (CER), Heat Stress (HS), , Reactive Oxygen Species (ROS), Resource Use Efficiency (RUE), Vapor Pressure Deficit (VPD),Water Use Efficiency (WUE)

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## Abstract

Climate is undoubtedly an uncontrollable agent which influences crop productivity. Cereal crops are very important with promising applications to feed global mouth. Temperature has an essential role in approximately all crop growth and development trends. Hence, global warming is a prime challenge for numerous cereal grain crops. A change in global climate patterns poses serious threats to cereal crop productivity which will ultimately challenge the already compromised worldwide food security. Negative impacts of heat stress on major cereal food crops is experienced in different regions of the world that is responsible for reduction in photosynthesis and enhanced leaf senescence rate and it is considered increasingly robust. Plants exposure to extreme temperatures during reproductive stages adversely affects grain productivity across all cereal crops. This will condemn resource-poor farmer communities having very low productivity towards extreme poverty, making them vulnerable to hunger and prompting their migration. Therefore, efficient development of agricultural industries is choice of the time for an overall refinement of the economy, employment generation, decrease in rural poverty and macroeconomic constancy.

## 1. Introduction

Anthropogenic climate change has definite implications on numerous sectors of life and among them agriculture sector retains crucially important place because it provides all other sectors with basic necessities and raw materials. LEPPA NEN et al., (2014) reported that climate has obvious and intuitive implications on agriculture sector. Climate change induced elevated temperatures have experienced across various regions of the world (Weisheimer and Palmer 2005; Tebaldi et al., 2006; Battisti and Naylor 2009; Yadav et al., 2015). It is predicted that world would experience average rise in temperature ranging from 1-3.7 ◦C by the end of this century (Pachauri et al., 2014). Global crop productivity is highly vulnerable to these changing trends as elevated temperatures poses serious negative impacts ( Rötter and Van de Geijn, 1999; Thomashow, 1999; Ciais et al., 2005; Reidsma et al., 2009; Schlenker and Roberts, 2009; Lobell et al., 2013) and potentially affect several vital processes such as, dry matter partitioning (Zhao et al., 2013), respiration and root growth (Kaspar and Bland, 1992; Atkin and Tjoelker, 2003), photosynthetic performance (Sage et al., 2011), plant developing patterns (Wolkovich et al., 2012) and transpiration etc. (Crawford et al., 2012).

Crop productivity will be affected to great extent due to alterations in critical abiotic factors including temperature, precipitation, solar radiation and $CO_2$. These factors are involved in several regulatory mechanisms like growth and development, weather induced changes, pest infestations (Cammell and Knight, 1992) associated disease complications (Fand et al., 2012), water requirements (Panda et al., 2003), increased prices of agriculture products in global agriculture industry and elevated proportion of fertilizers consumption. Nevertheless, the impacts have enough broad spectrum that the entire consequences of global warming cannot be even predicted. Lobell and Field (2007) documented that between 1962 to 2002 wheat yields have been reduced greatly due to increasing temperatures. Accordingly, during 1980-2011, these decrease wheat productivity trends attributed with extreme temperature events have been also reported by Gourdji et al., (2013) across various regions of the world such as South Asia, South America and Central Asia. Furthermore, several other studies accomplished by Asseng et al., (2009); Lizana and Calderini (2013); García et al., (2015) also highlighted that wheat yield has been negatively impacted by rising temperatures that cause adverse effects on biomass production (Calderini et al., 1999; Peltonen-Sainio et al., 2007; Sadras and Slafer, 2012). A past-50-year analysis of maize in France indicated yield variability since 2000 that is mainly attributed to daily maximum temperatures (Hawkins et al., 2013). Henceforth, rice crop is also sensitive to elevated night temperatures and these problems will be intensified because temperature will be increased further in future owing to climate change (Tebaldi et al., 2006). Another analysis based on the data obtained from historical stations of China revealed that a 4.6% of rice yield reduction per 1°C has occurred that is linked with elevation of night time temperatures (Tao et al., 2006). Over and above, increase in minimum night temperatures also reported to impact the yield of rice indica cultivar observed during a 25-year period in Philippines (Peng et al., 2004). It is predicted that the increase in global average temperatures would cause significant yield reductions (Hatfield et al., 2011; Lobell and Gourdji 2012).

In southern hemisphere Parry et al., (2007) noted elevation of 1-4°C in daily temperatures during the end spring season to middle of summers and this elevated temperature reduce crop productivity mainly by cutting-down the time length for phenophases ultimately decreasing the yield (Fuhrer, 2003; Ortiz, 2008; Hatfield and Prueger, 2015). Moreover, global climate models has suggested that tropical and subtropical regions will expect to be great victims of the upcoming HS (Battisti and Naylor, 2009). Grain yield is the integration of two components that are, grain average weight and grain yield/$m^2$, however, in terms of grain crop productivity, yield is mainly attributed to grain number ( Peltonen-Sainio et al., 2007; Sadras 2007; Araus et al., 2008; Gambín and Borrás, 2010). During grain set periods, crop resources are basically distributed between previously mentioned components i.e. grain average weight and grain yield which reflect a trade-off between them (Gambín and Borrás, 2010) along with variations in per grain assimilation (Gambín et al., 2006).

The term heat stress generally employed to depict the negative impacts of high temperatures on plant growth. Porter and Gawith (1999); Luo (2011); Moriondo et al., (2011) defined heat stress as short episodes of higher temperatures far from the typically experienced range. (Wheeler et al., 2000; Porter and Semenov, 2005) depicted that crops are vulnerable to higher temperatures especially during flowering periods. Some authors defined heat stress; event of elevated temperatures causing in great crop yield reductions that is irreversible too (Wahid et al., 2007) however, Al-Khatib and Paulsen (1984); Wheeler et al., (2000); Moriondo et al., (2011) explained that these yield reductions are attributed to significant production decline in viable seeds as well as rapid leaf senescence that causes yield reduction by shrinking grain filling durations  Over and above, by some authors HS; regular crop yield response to temperature extremes happening after a threshold is exceled that is apparent in large panel datasets analysis (Schlenker and Roberts 2009; Lobell et al., 2011).

From this lack of uniformity in HS definitions it can evaluated how much diversity lies in aforementioned definitions which demand the detailed evaluation through in-depth studies that will aid in illustration of crops` particular attributes. Probably, it might also reflect the restrictions of our anticipation regarding the phenomena of higher temperature impacts on crop yield. Such impacts are characterized as the integration of various mechanisms taking place at the organelles and molecular scales all having different temperature sensitive criteria (Sage and Kubien, 2007) coupled with their interactive association with processes like including assimilation, partitioning and transpiration (Ferrise et al., 2011). In this review, we analyzed the temperature effects on these different vital cereal grain crops for understanding how to adequately give a representation of heat stress on crop productivity.

## 2. Impacts of elevated temperature on maize

As an important food crop 'maize' also has prominent biotic (humans, animals, birds, microbes etc.) and abiotic limitations (climate change, soil, water quantity and quality, of nutrients e.g. NPK, and their availability, precipitation, wind, solar radiation etc.) in East African countries as well as in world (Mwalusepo et al., 2015). Although the social environmental factors i.e. household factors, age, gender etc. generally not regarded as potential factors which influence maize productivity.

Unlike wheat, in which HS affects both its grain number and weight, it largely affects maize grain number hence, maize yield determination is linked with grain numbering trends (Otegui and Bonhomme, 1998). Moreover, maize productivity is extremely sensitive to high temperatures particularly on flowering phase (Edreira and Otegui, 2013). The decline in grain number in fact associated with inadequate assimilation supply that occurs due to less photosynthesis coupled with increased respiration as well as owing to high temperature influences on reproduction phenomena (Edreira and Otegui, 2013). Maize exposed to HS (30–36 ◦C) during flowering periods appeared with decreased anthesis-silking intervals (Edreira et al., 2011).

Pollen viability of field grown plants significantly increased during exposures at 32 ◦C for 24 hours harvested from field and placed in controlled chambers. Herrero and Johnson (1981) highlighted maize exposure to 38 ◦C poses negative impacts on wide range of genotypes. In another study by Dupuis and Dumas (1990) found reduction in spikelet when exposed to temperatures above 35 ◦C in in vitro fertilization. Decrease pollen viability in maize occurred when exposed to 38 ◦C (Porter and Semenov, 2005). However, Otegui et al., (1995) analyzed lower kernel number even at low temperatures while excluding impacts on pollen availability and viability. Irregularities in kernel number according to Vega et al., (2001), linked with compromised plant growth during flowering stage that itself associated with active ear growth period and characterized as crucial period for estimation of kernel number during silking (Otegui and Bonhomme, 1998). High temperature (30 to 36 ◦C) when applied at silking stage caused reduction in kernel number as well as in final yield (Cicchino et al., 2010). Heat stress impacts were analyzed during flowering that also affected partitioning trends and removal of HS suggested that this observed response was transient because after this removal all assimilate were partitioned to the ear (Cicchino et al., 2010). However, Edreira and Otegui (2013) reported that higher temperature extremes 30 to 38 ◦C during flowering do not influence ear partitioning that might be due varietal diversity in kernel numbering patterns (Echarte and Tollenaar, 2006). Kernel formation/abortion occurs, as a result of reduction in assimilation rates that may be associated with sink limited cases. Both these cases can reduce kernel numbers which leads to lower harvest indexes (Cicchino et al., 2010). Eventually, these aforementioned results reveal the worth of source-sink ratio for observing high temperature implication on grain yield. Varietal differences in maize also exist in response to heat stress.

During pre-anthesis to silking stages, higher levels of kernel abortion were observed in temperate hybrids in comparison to tropical genotypes (Edreira and Otegui, 2013) at 33 to 40 ◦C, while all cultivars showed the similar patterns in reduction growth. However, smaller reduction in RUE was observed within tropical cross hybrids than temperate hybrids (Edreira and Otegui, 2012) that showed better adaptability of former to resist than temperate cultivars especially during flowering stages. Nevertheless, Wilhelm et al., (1999) stated that varietal variations usually became insignificant during grain filling stages when temperature exceeded 33.5 ◦C at day and 25 ◦C at night for prolonged periods.

## 3. Impacts of elevated temperature on rice

In highly favorable environments rice productivity is associated with sink capacity, grain weight (Hayashi et al., 2012), and varietal diversity (Fukushima et al., 2011). For obtaining better yields of indica variety, efficient translocation of carbohydrates within grains is very important (Yoshinaga et al., 2013). The response of rice yield to elevated temperature regimes related to variations in flowering patterns, seed set reduction and decrease grain weight. Mohammed and Tarpley (2009) documented that rice yield has high vulnerability to elevated temperatures. Daytime heat stress impacts on flowering lowered the anthesis period and accelerate the earlier peak flowering (Tao et al., 2006). In Figure 1 the impact of different temperature ranges on the quality and weight of rice grain has been given. The response of heat tolerant variety to daytime temperature range i.e. 40 to 42 ◦C was reported by alteration in usual flower opening schedule throughout entire day (Tao et al., 2006) but elevated night time temperatures has not been reported to initiate this response (Shi et al., 2013).

Jagadish et al., (2007) determined earlier flowering in both yield varieties i.e. indica and japonica when kept in a greenhouse chambers with exposure to high daytime temperature up to 36◦C. The employment of high temperature thresholds on different rice varieties exhibited different rates of seed sterility (Ishimaru et al., 2010). Pollen grain sensitivity to HS is greater than stigma as reported by Wassmann et al., (2009). Reduction in pollen production and pollen viability in gradient tunnels was encountered during exposure to average temperature increase from 22 ◦C to 28◦C (Prasad et al., 2006). Accordingly, Mohammady (2015) determined significant reduction in pollen germination percentages up to 20% when nighttime temperatures went up from 27 to 32◦C.

Adverse impacts of high daytime temperature 37.5 ◦C on pollen germination suggested seed set decline, however, seed set was extensively decreased than could be explained by pollen germination at higher temperatures 40◦C (Matsui et al., 2001). Henceforth, seed set decline occurred due to reduction in germinated pollen on stigma. No significant reduction was analyzed in spikelet number per panicle within eight hybrids during exposure to 40 to 42◦C temperatures at the day (Tao et al., 2006). However, Rang et al., (2011) reported that number of infertile grains increased coupled with partially developed grains (Tao et al., 2006). Temperatures from 27-32◦C causes reduction in panicle fertility up to 72% (Mohammed and Tarpley, 2009). Night-time temperatures ranging from 22 ◦C to 28◦C caused lower grain weight, seed set reduction and decrease spikelet number during a field experiment (Shi et al., 2013). Inadequate spikelet formation in fact associated with photosynthesis insufficiency under heat stress (Prasad et al., 2006). Exposure to 36◦C increased spikelet number in indica variety however it negatively affected japonica variety (Jagadish et al., 2007). In higher yielding cultivars large number of spikelet per area was reported with unfilled and unripened grains to large extent even in favorable environments (Hayashi et al., 2012). This highlights the crucial role of high source activity (assimilation/translocation) together with spikelet numbers for obtaining optimum yields. Reduction in the duration of grain filling is involved in decreased grain weight (Nguyen et al., 2014) that is also correlated with enhanced panicle senescence instead of leaf senescence (Morita et al., 2004; Kim et al., 2011). Kim et al., (2011) observed reduction in grain filling period of wheat is influenced by limited sink capacity rather leaf senescence. The influence of elevated temperatures on the rate grain filling is to some extent unclear because initially it showed positive impacts (Tashiro and Wardlaw, 1989) however, as temperature goes up grain filling decreased in response to lowered photosynthesis or translocation (Tashiro and Wardlaw, 1989).

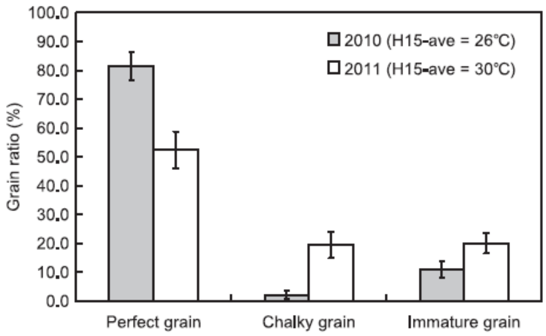


**Figure. 1 Rice quality variations in 2010 & 2011. *n* = 16. H15-ave were 26 °C in 2010 and 30 °C in 2011. H15-ave is characterized as average temperature during 0–15 days after. This data of H15-ave were collected from Central Weather Bureau (Wu et al., 2016).**

## 4. Impacts of elevated temperature on wheat

Wheat is a member of the family *Poaceae* and from genus *Triticum.* It is self-pollinated long day and annual, crop. It retains the title of "world most worthful food crop with highest cultivated land in comparison to others (Mohammady, 2015). Wheat yield is negatively affected by heat stress in arid, semiarid, tropical and subtropical areas of the world (Rehman et al., 2009). Wheat yield reduction associated with exposure to higher temperatures has been reported in various studies (Stone and Nicolas, 1994; Semenov, 2009). Most thermosensitive stage in wheat crop is anthesis (FERRIS et al., 1998; Porter and Gawith 1999; Farooq et al., 2011; Luo 2011) which affects wheat quality (Spiertz et al., 2006). Elevated temperatures accelerate patterns of plant development (Blum et al., 2001), decrease photosynthetic rates (Salvucci and Crafts-Brandner, 2004) and also negatively impact reproductive processes (Farooq et al., 2011). Empirical evidences have supported the relationship between higher temperatures during flowering with adverse effects on crop yield (FERRIS et al. 1998; Barnabás et al., 2008).

During wheat flowering periods, 31◦C is regarded as optimal upper limit at which grain number does not affected (Porter and Gawith, 1999) with sensitivity dependency on developmental phase (Dias and Lidon 2009; Wang et al., 2011), genotype attributes (Dias et al., 2011) and watering trends of crops (Atkinson and Urwin, 2012). The schedule of high temperature events i.e. (>30 C) cause grain number reduction, as described by Ortiz (2008) and (Fischer 1985) right before 20-days and after 10 days of anthesis stage and during the period of anthesis i.e. before 5 & after 2 days have special sensitivity (Wheeler et al., 1996). Anthesis vulnerability towards compromised grain yield is actually linked with repercussions on fertility strength of pollens (FERRIS et al., 1998; Calderini et al., 1999) as well as increased proportion of sterile grains which that are adversely affected when temperatures within the range of 27-31◦C in mid-anthesis (Mitchell et al., 1993).

Heat stress not only causes grain abortion and pollen fertility, but it also promotes crop development rates which stimulate the onset of anthesis and double ridge appearance eventually causing fewer spikelet per spike and also grains per spikelet (McMaster, 1997). The duration and rate of grain filling influence grain weight (Barnabás et al., 2008) and grain filling is characterized by the extent of current assimilate production by the function of photosynthesis (Blum et al.,1994), and relocation compounds that contain nitrogen and carbohydrates coupled with their transportation to ear (Plaut et al., 2004). In Australia, the grain filling patterns of 75 wheat cultivars were negatively affected by short episodes of higher temperatures i.e. 35 ◦C caused individual grain weight to decline up to 23% to 37% (Stone and Nicolas, 1994). Grain weight was reduced when temperature exceeded 34 ◦C by reduction in photosynthesis (Blum, 1986), less period available for grain filling and decrease in biosynthesis of starch in the endosperm cells (Jenner, 1994). Also, high temperatures are expected to promote grain dry matter accumulation rate. Stone and Nicolas (1995); Dias and Lidon (2009) described that this loss during grain filling cannot be sufficiently compensated.

Temperature above 25◦C decreases the period of wheat grain filling up to 12 days (Yin et al., 2009). Genotype is pronounced regarded as dominant factor with potential to influence grain filling dynamics (Hays et al., 2007). Temperature regime around 38 ◦C caused grain weight reduction of 13% during initial grain development times among thermo-sensitive cultivars of wheat than thermostable cultivars that have optimum range of 16-21 ◦C (Ciaffi et al., 1996). Leaf senescence rates goes up when temperature rises from 35 ◦C (Harding et al., 1990). Day and night temperature of 35/25 ◦C shortens the time for grain development due to senescence acceleration which is related to reduce photosynthetic process (Al-Khatib and Paulsen, 1984). Daily temperature differences i.e. 34 ◦C than 22 ◦C improvised leaves senescence in wheat exposed to HS in comparison to favorable conditions i.e. 26 ◦C/14 ◦C that caused significant delay in senescence (Zhao et al., 2007).

## 5. Impacts of heat stress on warm season crops

Rice is regarded as an important cereal crop in subtropical and tropical and regions especially in South-East Asia South Asia and is also vulnerable to increasing HS (Manigbas and Sebastian, 2007; Jagadish et al., 2012). The emergence trends of rice seedlings are restricted when temperature ranges above 40 °C (Yoshida et al., 1981; Akman, 2009). With the rise of each 1°C rice yield reduced approximately 10% during growth periods (Peng et al., 2014) and rice biomass production decreased up to 20% during continuous exposure to 2 °C (Ziska and Manalo, 1996). In another study, rice yield decreased about 6.7% during the growth period with average 1°C temperature rise (Lyman et al., 2013). Moreover, (Yoshida et al., 1981) noted when temperature rose above 32°C/25°C it adversely affected dry weight content, plant height and tiller number as well. Likewise, elevated temperature above (33°C) spikelet sterility was notably influenced and grain emptiness trends has been reported when temperature exceeded 35°C (Matsui et al., 2001; Jagadish et al., 2007).

Embryonic protein synthesis was impaired in maize when temperature raised above 37 °C ultimately inhibiting the germination (Rilkey, 1981). Weaich et al., (1996); Akman (2009) stated that growth of coleoptile in maize was completely diminished when temperature cross 45°C. Similarly, a significant decline in maize photosynthesis and enhancement in respiration was evaluated that is attributed to HS impacts (Crafts-Brandner and Salvucci, 2002) responsible for and inadequate kernel development and pollen sterility (Schoper et al., 1987; Cheikh and Jones, 1994). In addition, HS prevalence during seed filling stages of soybean lowered seedling strength and germination (Egli et al, 2005) and temperature above 30 °C in tropical humid conditions has pernicious impacts on soybean seed production (Lindey and Thomson, 2012). McDonald and Paulsen (1997) noted that growth and photosynthesis in different legumes also vulnerable to rising temperature e.g. microsporogenesis in common bean is halted when temperature goes beyond 30°C hampers (Porch and Jahn, 2001; Rainey and Griffiths, 2005; Porch, 2006).

Besides, distinguishable evidences of temperature influence on legumes, crops such as cotton (Singh et al., 2007a) and sorghum (Eastin et al., 1983; Prasad et al., 2008) has high vulnerability towards temperature. (Peacock et al., 1990) depicted that the germination and epicotyl emergence in sorghum was negatively affected when temperature in seed zone of soil exceeded 45°C. Likewise, Camejo et al., (2005) concluded that the seedling emergence in tomato was terminated when temperature exceeded 30°C. Furthermore, several studies (Peet et al., 1998; Adams et al., 2001; Pressman et al., 2002; Camejo et al., 2005) highlighted that HS halts fruit development, photosynthetic rate and pollen grain viability.

## 6. Impact of heat stress on cool season crops

HS is a major concern for cool-season crop especially for wheat-growing regions of cooler north territory (Liu et al., 2014). Joshi et al., (2007) and Singh et al., (2007) documented several wheat growing regions of South Asia are vulnerable to HS. Significant wheat yield reduction has been attributed to curtailing cool periods (Joshi et al., 2007; Rane et al., 2007). Likewise, Asseng et al.,(2011) documented that temperature variability of ~2 °C during growing season can cause 50% yield reductions in Australia. The germination of wheat seeds gets affected by HS that then impairs the enzymatic activity linked with breakdown of starch (Essemine et al., 2010). Frequent elevated temperature episodes also cause certain anomalies in wheat crop such decline in biomass production, starch biosynthesis disruption during grain-filling stage (Reynolds and Trethowan, 2007), pollen sterility and degradation of tapetum during meiosis (Saini et al., 1984; Sakata et al., 2000; Zinn et al., 2010) and abnormal ovary development (Saini et al., 1983). The relative impact of HS on three major food crops (wheat, maize and rice) has been given shown in Figure 2. Temperature above 33 and 24.4°C are harmful for germination of chickpea and lentil seeds orderly (Covell et al., 1986), while several damages were encountered in lettuce in response to elevated soil temperature above 32°C (Gray, 1975). Furthermore, study conducted by Young et al (2004) highlighted the impacts of HS including inadequate seed production in *Brassica napus* L. that is attributed to micro- and megagametophyte fertility and growth impasse and disruption in photosynthetic performance in *Brassica juncea* (Hayat et al., 2009).

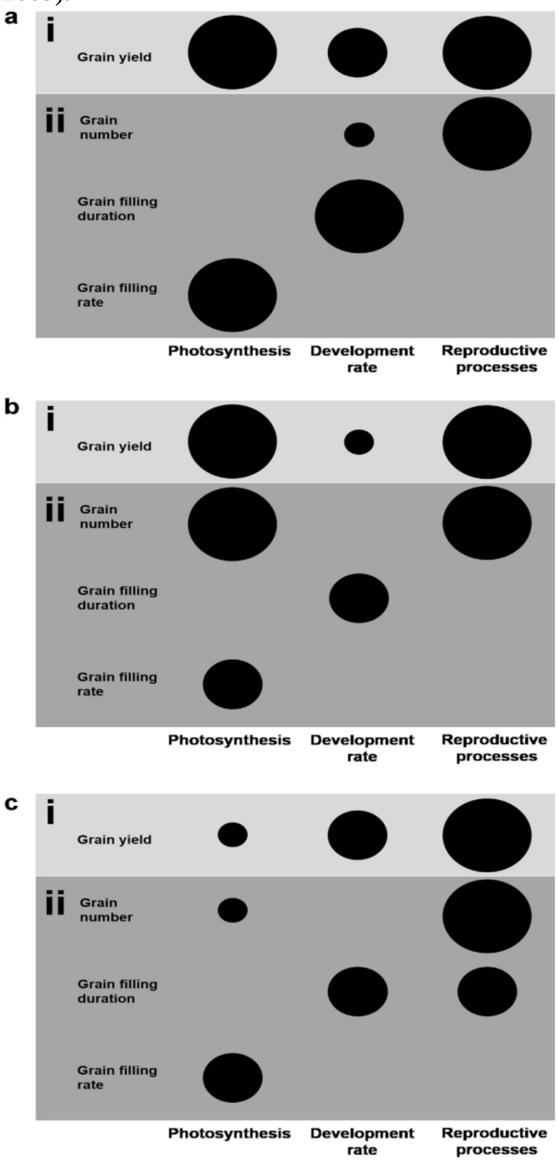


**Figure 2 a, b, c. The relative impact of HS on fundamental physiological processes of cereal**

**crops including (i) yield (ii) yield determinants including grain number, grain filling duration, and grain filling rate are presented by the size of the circle. Large and small circles denoted to relatively large and small repercussions of HS, respectively for a wheat, b maize, and rice (Rezaei et al., 2015)**

## 7. Diminished productivity and socioeconomic challenges under climate variability

Farmers socio-economic life is also affected by low agricultural productivity. In developing countries, agriculture industry is a fundamental sector for a large proportion of people for sustaining their life with very basic needs. Low agricultural productivity has pernicious effects on farmers economic viability which deteriorates farmer` life quality standards. On this base it can be strongly said that the life style of farmers is directly linked with agricultural productivity because diminished agricultural productivity also reason of low-income by disturbing financial life in accordance with today's inflation. Therefore, if the contribution of agricultural sector does not meet sustainable approaches it will ultimately impact public life with more challenging trends. Finally, it will push low and average-income families to extreme poverty, making them vulnerable to hunger and prompting their migration to towns and cities exerting more pressure on already diminished resources and influencing the carrying capacity of ecosystems. In this backdrop, educational factor is to be thoughtful as a good parameter in terms of greater awareness of farming cultures, the schedule of "how and when" the application of fertilizers and pesticides as well as the efficient seed storage conditions (Justin, 2015).

## 8. Conclusion

Climate change affects a wide range of sustainable development issues such as education, employment, food security, gender equality, health, housing and poverty, incomes and livelihoods. The study on heat shock gives the dimensions that we should enhance our anticipation about temperature threshold implications on plant performance to grain set and also alteration of grain-filling period. In this regard, a wise approach for eliminating temperature impact should be taken which encompasses the suitable selection of varieties having capability to shed their pollen in early morning times when temperatures are comparatively better and compatible. The occurrence of temperature extremes will become frequent and increase in magnitude with increasing negative impacts on plant growth and development. Cereal grain yields are more sensitive to increasing temperature than vegetative growth that is coupled with elevation in minimum temperature range henceforth, results from controlled environment studies revealed decline in maize productivity pertaining to higher temperature exposures during the grain-filling period. Temperature influence the soil water status which would suggest that variation in precipitate conjoined with warm temperatures might involve in decrease grain production. Finally, to quantify the potential interactive relations between temperature and soil water availability across germplasm not only among species but also within a species, more research is needed for evaluating the smart adaptation approaches for eliminating the harms of extreme temperature regimes.

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