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Review

Paradigms of climate change impacts on some major food sources of the world: A review on current knowledge and future prospects

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ABSTRACT

Due to the adverse impacts of climate change on earth systems the research in this field has been profoundly taken a part in all scientific arenas since last few decades. The deleterious impacts of climate change on agricultural production are challenging the food security of the world in terms of quantity and quality both. Wheat, rice, maize, vegetables, fruits and fish-food provide food security for more than half of the world and are under immense pressure of changing climate. This review is an overview of the significant impacts associated with climate change on these food sources. In present synthesis, various phenological, physiological, biochemical and reproductive responses in major food crops have been summarized emphasizing the vulnerable growth and development stages. Winter and summer sensitivity responses, and morpho-biochemical acclimation patterns have also been summarized. Sustenance in wheat and rice production is evident but impacts of increasing temperatures are negating this on bio-physiological level impacts. Maize crops are experiencing more impacts on yield as compared to wheat and rice. Fruits and vegetable production is highly vulnerable to climate change at their reproductive stages and also due to more disease prevalence. Fisheries as a critical animal food source; is in extreme danger as apparent changes in their habitat and unmanageable environmental conditions are producing extreme losses. This review also provides an account of stress responses and useful adaptive measures. This synthesis may be helpful in understanding manifold dimensions and interactions of climate change impacts on selected major food sources of the world.

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1. Introduction

Climate variability has been and continues to be, the principal source of fluctuations in global food production in developing countries (Oseni and Masarirambi, 2011). The Earth's climate has warmed by approximately 0.6 °C over the past 100 years with two main periods of warming, between 1910 and 1945 and from 1976 onwards and is greater than any other time during the last 1000 years (IPCC, 2014). Undoubtedly, agricultural production is going to be affected due to its consequences and the magnitude of which on crop yields will vary locally due to regional differences in both natural and anthropogenic factors that control plant responses (Rustad, 2008; Wei et al., 2014). Coupled with resource scarcity of land, water, energy, and nutrients, declining soil quality, increased greenhouse gas emissions and surface water eutrophication, climate change will affect crop production in a great deal (Fan et al., 2011; Tripathi et al., 2014). Changing temporal and spatial trends of hydro-climatic variables, rising sea levels and increasing incidence of extreme events pose new risks to future food insecurity in all parts of the globe (Chen et al., 2015; Zhao et al., 2015). Anomalies in temperature and climatic regime of our earth system have raised the concerns to think global climate change as a strongest stressor for the agriculture and world food production since plants are directly related and respond to environment CO_2 and temperature (Kersebaum and Nendel, 2014). Therefore, the potential impacts of climate change on food security must therefore be viewed within the larger framework of changing earth system dynamics and multiple socio-economic and environmental variables.

Various critical direct and indirect consequences of global climate change on crop production can be seen due to the rising CO_2 and temperature and unpredictable rainfall disturbing the food security aspects of the world (Poudel and Kotani, 2013). Consequently it becomes quite important to examine the changes happening at different stages of the crop growth and development and their impact on the production either in the form of quality or quantity. As this subject has gained enormous importance in recent times with growing numbers of specific studies of the impacts of climate change on various food items; multidisciplinary synthesis of the knowledge of climate impacts on major food sources of the world is needed.

1.1. Climate change and its current scenario

The 'climate' may be referred as the characteristic weather conditions (viz. air temperature, precipitations, atmospheric pressure, humidity, wind, sunshine and cloud cover) of the earth's lower surface atmosphere at a specific location. Any change compared to prior observations in an existing observation record of the systematic measurements of these phenomena at a specific location over several years may be ascertained as climate change. However, an internationally agreed definition of the term "climate change" is still desirable which on different international platforms is regarded as (i) only human-induced changes in the climate system (UNFCCC, 2006), or (ii) all changes in the climate system, including the drivers of change, the changes themselves and their effects (GCOS, 2012); or (iii) long-term changes in average weather conditions (WMO).

The world is now frequently experiencing many unprecedented changes in climate due to warming of the earth's system since last five decades. The assessment report of IPCC (2014, AR-V) identifies the changes as well as gives various projections in current climatic variables. Each of the last three decades has been successively warmer than any preceding decade since 1850 imparting warmest 30-year period (1983–2012) in the Northern Hemisphere, in last 1400 years (IPCC, 2014). The atmospheric concentration of CO_2 has increased to the level of 396.48 μmol mol^{-1} in 2013 (ESRL-NOAA data, Fig. 1A) from its pre-industrial level of 280 ppm and is projected to reach 550 ppm by the middle of this century which may escalate up to 700 μmol mol^{-1} by the end of this century

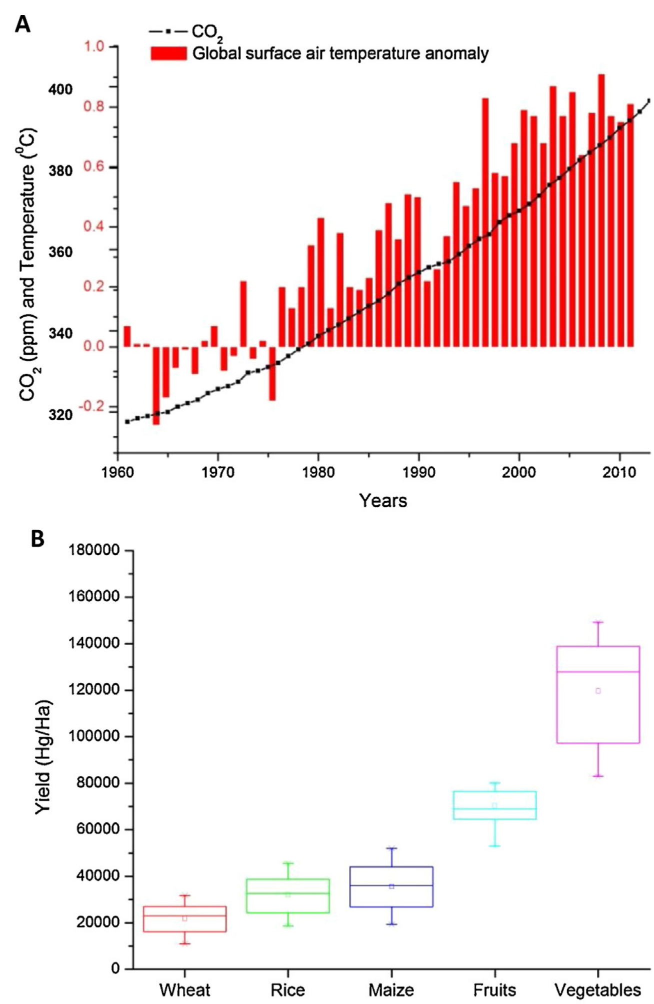

Fig. 1. (A) Annual mean of global surface air temperature anomaly (Base period: 1951–1980) and global CO_2 concentration since 1961–2013; shows equivalent increasing trends both in CO_2 concentration and temperature, indicating escalating warming of Earth systems (Data source: GISTEMP and ESRL, NOAA data). (B) The box chart shows variability in yield worldwide in selected food crops (excluding fisheries) since 1961–2012. Yield in selected food crops are showing departures from mean yield with respect to their minimum and maximum yield (Data source: FAO data). The boxes show first and third quartiles while whiskers show 5–95% intervals. The line in the boxes represents the median, and the small boxes, the mean value.

(Raupach et al., 2007). Evidently, the Earth's system shows a warming of 0.85 °C, over the period 1880–2012 and the ocean warming is also increasing on a global scale and is largest near the surface; and the upper 75 m warmed by 0.11 °C per decade over the period 1971–2010 (IPCC, 2014). Further increase in GHGs will have a significant impact on global climate since in unmodified conditions of current energy uses; mean annual global surface air temperature will be raised by 1.5–4 °C (Wheeler and von Braun, 2013). This will have far reaching consequences on each type of ecosystems of the world including agro-ecosystems hence is dangerous for the food security of growing world's population.

1.2. Climate change and agriculture

Despite of the huge importance of the industrial production in the world, agriculture has an essential role in ensuring the food security and welfare of growing population (Rustad, 2008). Climate change associated impact on global food security is a threat with which the world will have to deal in the twenty-first century (Myers et al., 2014). Climate change will probably have direct impact on tropical and temperate regions where high temperature or inadequate rain often limits crop productivity (Wheeler and von Braun, 2013). Changed weather conditions will have serious impacts on food availability, accessibility, utilization and food system stability (Gu et al., 2010) and thus food security will be affected. As the growth and development of any plant depends on various environmental factors and their interaction (such as temperature, precipitation, moisture and pressure, etc.) (Cutforth et al., 2007); a plant will behave differently in different interactions and will show different impacts. The impacts will be either visual or changes will happen in its physiology and at the level of other biological processes (Cicchino et al., 2013). The quantitative and qualitative estimates of climate change impacts on crop yields are derived from various crop simulation models for almost all continents (Parry et al., 2004; Krishnan et al., 2007; Table 1). These simulations include higher temperatures, changes in precipitation and higher atmospheric CO_2 concentrations to make advance assessment of climate effects across a range of crops (Reidsma et al., 2010). However, some studies show that in current climatic scenario the increasing levels of the CO_2 may give some positive impacts on the crop production due to higher net photosynthetic rates and reduced transpiration but at the same time increase in the temperature negates this and different crops show variable impacts (Gu et al., 2010; Mishra et al., 2013; Table 1). On the other hand, increases in the level, timing and variability of precipitation may benefit semi-arid and other water-short areas by increasing soil moisture, but can aggravate problems in water excess regions (Schlenker and Lobell, 2010). Meanwhile a reduction in rainfall could have the opposite effect as well (Braun and Markus, 2012). Various specific crop and climate scenarios for the selected food sources in this assessment have been given here to understand the projected specific impacts of the changing climate on the particular food sources on different continents (Table 1).

Based on recent literatures and published data, this synthesis seeks to elucidate the potential impacts on different bio-physical processes of some important food sources of the world to understand the impact scales and their dimensions affecting the yield over the globe. Our primary goal here is to review observations of climate change impacts occurring on major food sources across the world and to find out evidences on crop responses to different kinds of stress produced due to changes in climatic factors. This deals with the various dimensions of climate change impacts on some major food grains (wheat, rice and maize), examines and points out the major changes happening at different level of vegetable and fruit crops and integrates the various findings of published researches on the impact of climate change on fish-food which is also one of the major sectors fulfilling food demand across the world. It also tries to find out the winter and summer sensitivity differences in selected food sources, ways of stress responses and acclimation patterns to fight with the climate change induced stresses. Major climate change adaptive and mitigative strategies to cope up with the impacts have also been illustrated in brief.

2. Impact of climate change on major food sources of the world

2.1. Impacts on major food grains

The wheat, rice, and maize are among the six most widely grown crops in the world (Lobell et al., 2011). Production of these crops accounts for over 40% of global cropland area, 55% of non-meat calories and over 70% of animal feed (FAO, 2008). Historical climate and crop data have been used to indicate climatic impacts on yields of these grains in many countries of the world (Schlenker and Lobell, 2010). In the following sections three major crops of the world and their responses under the climate change has been illustrated by taking into account various literatures and reports available.

2.1.1. Impacts on wheat

Various studies report the projections of impact of climate change on wheat (*Triticum aestivum* L.) production under different simulation models in different continents (Parry et al., 2004; Altenbach, 2012; Kersebaum and Nendel, 2014 Table 1). Under various climate change scenarios the major influencing factor is availability and management of soil water reserves of winter wheat, especially in frequently occurring extreme events such as heat waves and droughts with decrease in annual soil and groundwater recharge (Barnett et al., 2012; Elliott et al., 2014). However, it is expected that future climate change will affect wheat yields but is uncertain whether it will result in more positive impacts or negative ones. This is due to the opposing effects of temperature, precipitation and CO_2 concentration on physiological processes of wheat growth and development (Mishra et al., 2013; Kersebaum and Nendel, 2014). While CO_2 fertilization effects will induce more photosynthetic production whereas higher temperatures can reduce net carbon gain by increasing plant respiration more than photosynthesis (Högy and Fangmeier, 2008). The light-saturated photosynthesis rate of C_3 cereals such as wheat is highest for temperatures about 20–32 °C, while a steep nonlinear increase is noticed in total crop respiration for temperatures from 15 to 40 °C, followed by a rapid and nearly linear decline (Porter and Semenov, 2005). However, reduction in yields with higher temperature has been found worldwide (Lobell and Burke, 2008). In China, increase in temperature was correlated not only with lower but also with higher yields of wheat (Zhang and Huang, 2012). Lobell and Burke (2008) reported negative correlation between wheat yields and temperature but a positive correlation with precipitation reflecting that precipitation has a more positive impact on wheat yield than temperature.

Studies have also been carried out on the impact of climate variability on wheat production changes as functions of different environmental parameters (Reyenga et al., 2001; Alexandrov et al., 2002). Decrease in the production of wheat under the influence of changing climatic conditions have been reported from many agrological regions (Janjua et al., 2010). However, these trends in reduction may seem small when expressed as a percentage of current yields. The absolute losses in global wheat production due to warming trends since 1981 are substantial which would have been roughly 2–3% higher without climate trends since 1981 (Lobell and Field, 2007). There are various studies elucidating

Table 1
Various significant impacts of climate change under different climate change/crop scenarios on different continents of the world.

Selected food sources	Continents							
		Africa	Antarctica	Asia	Australia	Europe	North America	South America
Wheat	Crop-climate models	HADCM3, DSSAT, PEGASUS, IPSL-CM5A-LR	–	SRES A1B and A2, CropSyst, MAGNET, CWHEAT2	MK2, DOE-PCM, APSIM-Nwheat	CMIP3&5, EU-ENSEMBLES, RCP8.5, HERMES, EuroWheat	DRSTIL, HADCM3, SoilN Wheat, CSM-CROPSIM-CERES-Wheat V4.5	HADCM3, CWHEAT2, APSIM-Nwheat
	Specific impacts	Median response to climate change is a negative impact with major yield losses	–	Simulated yields show increases. An increased risk of flower sterility & reduction in yield	Increased average growing-season temperatures in the main wheat growing regions, this can cause reductions in grain production of up to 50%.	Occurrence of adverse conditions might substantially increase by 2060, northward expansion of suitable cropping areas	Shifts in wheat production into environments once considered too arid, too variable, and too harsh to cultivate	An increased risk of reduction in yield,
	References	Krishnan et al. (2007); Estes et al. (2013)	–	Krishnan et al. (2007); Nelson et al. (2014)	Luo et al. (2005); Asseng et al. (2011)	Kersebaum and Nendel, 2014; Trnka et al. (2014)	Olmstead and Rhode (2011); Li et al. (2013)	Barros et al. (2014); Nelson et al. (2014)
Maize	Crop-climate models	PEGASUS, DSSAT, CERES-Maize	–	CERES, Cropsyst, InfoCrop, Hybrid-Maize Model	PEGASUS, APSIM, CMIP5, Agro-IBIS	EU-ENSEMBLES, HADCM2 & 3, AO-GCM	BIOCLIM-ECHAM-A2, GARP-ECHAM-A2, SVM-GFDL, CropGro	MarkSim, CERES maize, Cropsyst
	Specific impacts	Atleast 10% reduction in the potential maize growing areas	–	Projected mean change in production ranges from 10–16% as well as increase in some areas	Weather extremes may cause ~10–80% variation in production	Yield stagnation and increased yield variability, reduction of the growing period	Significant reduction of potential distribution areas by 2030 and 2050	Estimated overall reduction may range from 8 to 10% by 2055
	References	Krishnan et al. (2007); Charles, 2014	–	Knox et al. (2012)	Anwar et al. (2015); Ummenhofer et al. (2015)	Olesen et al. (2011)	Ureta et al. (2012)	Jones and Thornton (2003); Marengo et al. (2014)
Rice	Crop-climate models	ORYZA2000, PEGASUS, DSSAT, IPSL-CM5A-LR,	–	MAGNET, SIMRIW, CERES-RICE, CCSM3	HADCM3, ECHAM3/LSG, CERES-Rice 4.0, APSIM	EU-ENSEMBLES, LPJmL, IWDhydro	RICESYS, ORYZA1N, CropGro,	PEGASUS, MAGNET, CERES-RICE
	Specific impacts	There will be large yield gaps between potential and actual yields	–	Temperature increase may decrease rice yield compared to normal condition scenario	Negative impact of climate change is mainly due to advances in crop phenology	Major losses in the form of Fresh water limitations in some irrigated regions	Greater water losses from higher evapotranspiration	Shift of rice to more favourable production zones due to reduced rainfall, increased temperature
	References	Krishnan et al. (2007); Dufresne et al. (2013)	–	Lee et al. (2012); Nelson et al. (2014)	Luo et al. (2005); Anwar et al. (2015)	Jones et al. (2003); Elliott et al. (2014)	Eisenhaue et al. (2014)	Pinheiro et al. (2006)
Fruits and vegetables	Crop-climate models	SRES B2, IMPACT, GTAP-W, HADCM3	–	CSIRO-MK3, HadCM3, MIROC AFRCWHEAT2	CLIMEX, GENSECT, HADCM3, VineLOGIC	SRES A1B, FSSIM, DAE	FASOM, IMPACT	SRES A1B, CLIMEX
	Specific impacts	Varied impacts on rainfed and irrigated fruit and vegetable production, both positive as well as negative impacts, loss in winter chill	–	Delayed harvesting periods, impacts on postharvest quality causing tuber malformation, and changes in reducing sugars contents on potatoes	Disease outbreaks and changes in flowering-fruiting time, chilling requirement not being met in future warmer climates	Climate change may enhance pathogen contamination risk on leafy green vegetable, changes in yields	Potential impacts generally vary by latitude, reduction in southern crop growing areas and enhanced yield in northern areas, winter kill of fruit trees	Major impacts of ElNino and Southern oscillations
	References	Luedeling (2012); Calzadilla et al. (2013)	–	Moretti et al. (2010); Bandara and Cai (2014)	Webb et al. (2007)	Liu et al. (2013); Collier et al. (2014)	Alig et al. (2002); Motha and Baier (2005)	Marengo et al. (2014)

Table 1 (*Continued*)

Selected food sources		Continents						
		Africa	Antarctica	Asia	Australia	Europe	North America	South America
Fish-food	Crop-climate models	GTAP-W, GFDL's CM2	BE models- PROC DISCRIM, CSIRO2, SPACC	AquaMaps, GFDL's CM2, CMIP3-E	Mk3L-COAL, ERAEF	AORCM, GFDL's CM2, DBEMs, TOPAZ	BBN, CANESM2M, SD-SAM, PCM	HADCM3, ERAEF, PCM
	Specific impacts	Predicted increased productivity at high latitudes, decreased productivity at low/mid latitudes, increased productive potential in West Africa	Habitat change and ocean acidification will affect fishing capacity and primary fish production	Decrease in productive potential in South and Southeast Asia, substantial reduction in marine fish production	Wild populations appear more vulnerable than aquaculture, changes in habitat quality	Species invasion, northern seas are expected to switch from polar to more temperate species, also the opening of new fishing opportunities	High water temperature is the leading driver of potential declines in fish community	More Invasive species, range shifts on species level, changes in habitat quality and availibility
	References	Lam et al. (2012); Barange et al. (2014)	Mbogga et al. (2010); Cheung et al. (2013)	Barange et al. (2014)	Plagányi et al. (2011); Richards et al. (2015)	Philippart et al. (2011); Cheung et al. (2013)	Okey et al. (2014); Fayram et al. (2014)	Ficke et al. (2007); Allison et al. (2009)

variables through which these impacts can be tested and observed and for which wheat crops are sensitive to a change and interactions among them (Amthor, 2001). For instance, long-term changes in the soil fertility and soil water storage capacity, accelerated hydrological cycle exaggerated by a change in evapotranspiration, precipitation, the run-off and by any change in the intensity and frequency of floods and droughts can significantly modify the climate change impact on wheat production (Dai, 2006; Sheffield and Wood, 2012). These are the most important limiting factors in wheat productivity in semi-arid agricultural areas (Lal, 2009).

It is important to understand that physiological responses of increasing atmospheric CO_2 concentration known as CO_2 fertilization effect can produce larger and more vigorous plants, higher total dry matter yields and often greater quantities of harvestable product (Lobell and Field, 2007). This is due to increased CO_2 concentrations which affect plant growth directly through stimulation of photosynthesis and reduction of transpiration resulting improved water use efficiency (Ortiz et al., 2008). Elevated CO_2 may also increase positive effect of soil nitrogen on water use efficiency of wheat (Leakey et al., 2009). Studies have also shown that growth of wheat plants is proportional with CO_2 under water limited conditions affecting energy exchange. This depends on soil water availability and positively impacts wheat production (Jablonski et al., 2007). However, these positive impacts may be compensated by many other physiological and biochemical impacts owing to heat and water stress conditions.

Overall decreases have been reported for most macro and micronutrients in wheat under high CO_2 (DaMatta et al., 2010). In wheat, reductions in N, Ca, Mg, and S were consistently reported whereas P and K responded differently to different CO_2 enrichment experiments (Högy and Fangmeier, 2008). These reductions under drier climate may be attributed to the accumulation of carbohydrates and other organic compounds, reduced uptake of N from the soil under varied transpiration rates resulting from decreased stomatal conductance and impaired nitrate assimilation associated with decreases in the photorespiration pathway (Luo et al., 2005; Bloom, 2006). It may also lead to decreased leaf protein concentration (Dupont et al., 2006; Altenbach, 2012). Evidently, the increase in temperature have a larger effect than elevated CO_2 on carbohydrate composition with increased sucrose and slightly decreased stachyose; while glucose, raffinose and fructose show less or no significant change (DaMatta et al., 2010). Changes in average granule size owing to induced water stress due to low humidity, strong winds and high light intensity have also been noticed which may have a greater impact on grain yield during certain growth stages than similar stress at other growth stages (Hurkman & Wood, 2011). Significant differences in water potential among different wheat genotypes under water stress have also been reported for wheat cultivars in different countries (Elliott et al., 2014). The resulting reduced turgor pressure in wheat plants will slow down leaf expansion, branching and tillering before stomata-controlled processes are reduced (Farooq et al., 2009). The increasing temperature also affect the structure and gelatinization process of wheat starch where small increase in temperature (2–4 °C) may affect grain quality more than twice the effect of CO_2 since starch content, starch grain size and number and gelatinization may be altered in complex ways with temperature (Hurkman and Wood, 2011). Elevated temperature also affects the concentration of oleic acid and linolenic acid, non-starch and starch lipid fractions, changes in acyl lipid, proportions of the membrane glycosylglycerides and phos-phatidylcholine, gliadins and decreased glutenin content, (Tester and Sommerville, 2003; Wieser et al., 2008). High temperatures may down-regulate waxy proteins, allergen-like proteins and elongation factor while heat shock proteins (HSPs), α-amylases, glyceraldehyde-3-phosphate dehydrogenase (GADPH) and triosephosphate isomerase involved in glycolysis are up-regulated by high temperature (Luo et al., 2005; Altenbach, 2012).

Various reproductive changes in wheat crop are also seen due to high temperatures, which result in limiting plant growth and reducing grain yield. In some parts of the world, genetic progress in wheat breeds has been fairly counterbalanced by the unfavorable effects of climate change since the end of the 1980s (Oury et al., 2012). Short term exposure to extreme temperatures at any point before fertilization is much dangerous for many reproductive processes and consequently may decrease or prevent fertilization (Trnka et al., 2014). It has been observed that cell division stages of pollen and megaspore mother cell in wheat did not alter pollen germination, but guidance of pollen tube to the ovules may be prevented due to an increase in ovule abnormalities and a decrease in the proportion of functional ovules (Snider and Oosterhuis, 2011). This may have huge impact on what grain yield. Climatic impacts on post fertilization process result in pollen and anther sterility at the time of anthesis and thus restrict embryo development leading in reduction in grain numbers (Hedhly et al., 2009). After anthesis, high temperature stress affects the rate of grain filling leading to reductions in grain yield (Snider and Oosterhuis, 2011). Apart from these, effect of temperature on expression of genes encoding enzymes for starch biosynthesis in developing wheat endosperm were also reported indicating the effect of climate change on genetic levels as well (Hurkman and Wood, 2011).

Farmer's perceptions based studies in some parts of the world also point out the impacts of the shifting weather patterns affecting sowing and harvesting time and quality of wheat crops. Reduced fog, less winters and winter rains are some major variables which have been noticed by the farmers impacting the quality of wheat produce (Tripathi and Singh, 2013). Summarily it is quite complicated to discriminate whether climate change impacts on wheat are larger on negative side or positive but it is reasonably clear that changes in climate are playing crucial role in changing the various physiological and biochemical process of wheat growth and development which may have larger impacts on yield of wheat crops in recent future which is seeming quite sustainable at the moment.

2.1.2. Impacts on rice

Rice (*Oryza sativa* L.) is one of the main staple foods for over the half the world's population, providing 27% of dietary energy with 20% of dietary carbohydrate in the developing world (FAO, 2004). It is cultivated in at least 114, mostly developing, countries and is the primary source of income and employment for more than 100 million households in Asia and Africa (FAO, 2004). Droughts, floods, and typhoons are the major causes for fluctuation in production of rice as well as in its pricing worldwide (Pedersen et al., 2009; Sheffield and Wood, 2012). China and India account for more than half of the world's rice area, and, along with Indonesia, consume more than three-fourths of the global rice production (FAOSTAT, 2010). The changing climate has underscored the massive implications on rice; important for human nutrition, global food security, and alleviation of poverty (FAO, 2008). In general, an increase in CO_2 level was found to increase yields while increases in temperature reduced yields in some rice crop yield simulation models (Krishnan et al., 2007; Table 1). Some CO_2 sensitivity experiments of the rice indicated that an increase in CO_2 concentration leads to yield increase due to its fertilization effect and also enhances the water use efficiency of the paddy (Shimono et al., 2010). However, the temperature sensitivity experiments have shown that for a positive change in temperature up to 5 °C, there is a continuous decline in the yield (Endo et al., 2009). Increase in the rice yield has also been shown by some rainfall sensitivity experiments when the observed values of rainfall are near exponential but decrease in rainfall results in yield loss at a constant rate (Poudel and Kotani, 2013). Reports indicate that rice yield is more vulnerable under maximum temperature as compared to the minimum temperature while collective effects of maximum and minimum temperature are more significant compared to their individual effect on rice production (Basak, 2009). Farmer's observation in many agricultural areas report variability in rice production; strongly influenced by rainfall patterns and gradual shift in the fruiting and flowering season of rice crops (Tripathi and Singh, 2013).

In phenological impacts, visual appearance of successive leaves and shortening of the flowering time due to CO_2 enrichment has been reported in rice (Streck et al., 2008). The elevated CO_2 effects were also observed in the morphology of leaves, changing the number, density and size of stomata (Pedersen et al., 2009). High air temperature can result in the increase of leaves surface temperature, affecting photosynthesis of crop and restraining the root growth, which is expected to negate the positive effects of CO_2 fertilization (Gu et al., 2010; Poudel and Kotani, 2013). Thermal effect of temperature and photoperiod consequently affect successive leaf appearance and the rate of leaf area expansion (Streck et al., 2008). Physiologically, high temperature also affects the accumulation of dry matter, carbon and nitrogen (Kim et al., 2013) in the Kernel Rice (Kobayashi et al., 2007). In rice, amylose which is unresponsive to elevated CO_2 in combination with gelatinization temperature largely determines the grain quality (Terao et al., 2005). Elevated temperatures have been found to cause lower amylose content, decreased hardness of the rice grains or amylose may also increase at warmer temperatures increasing stickiness of rice grains (Counce et al., 2005). Within gliadins, ω-5gliadins and ω-1, 2gliadins are more prone towards high temperature stress in rice (Wieser et al., 2008). Elevated CO_2 (540–958 μmol mol^{-1}) may cause lower protein concentrations in rice (Taub et al., 2008). Proteome change in rice is envisaged at higher temperature (30–35 °C) especially for the lignification-related proteins and proteins related to protection which are regulated by temperature (Han et al., 2009; Kosová et al., 2011). High night temperatures have also affected the milling quality, grain dimensions, and starch branching in rice (Counce et al., 2005). Climate change has been also predicted to affect rice productivity by altering disease occurrence and insect infestations (Rosenzweig et al., 2001; Table 2). Elevated CO_2 and temperature will have striking effects on irrigated rice production, through indirect effects inducing insect pest attacks, diseases, and weed competition in the rice ecosystem and could also affect the vulnerability of rice to the important disease like rice blast and sheath blight (Kobayashi et al., 2007; Gregory et al., 2009; Table 2). It was found that glucose concentrations significantly increase in the foliage of rice under increased CO_2; making more favorable condition for insects to attack (Shimono et al., 2010).

On reproductive structures, the elevated temperatures have marked impacts as it may decreased crop yield due to spikelet sterility and the same happens with combined effect with CO_2 (Kim et al., 2011; Rang et al., 2011). This also results in the lower quality of rice grains because of reduced growth duration (Peng et al., 2004). Reduce grain-filling duration and enhanced respiratory losses are also observed during fertilization process (Fitzgerald and Resurreccion, 2009; Kim et al., 2011). The increased humidity and wind velocity changes due to climate change have immense impacts on viability of pollination and length of basal dehiscence of the theca in rice (Matsui et al., 2005; Jablonski et al., 2007). Rice kernel development is less responsive to temperature extremes, but is more sensitive to low temperature (Kim et al., 2011). Rice is hypersensitive to high-temperature stress during panicle development and meiosis causing anomalous pollen

Table 2
Various diseases and ailments of selected food sources induced due to changes in different climatic variables.

Selected food sources	Disease and pathogen interacting with changing climatic variables	References
Rice	Rice blast (*Pyricularia oryzae,Magnaporthe grisea, Magnaporthe oryzae*) Sheath blight (*Rhizoctonia solani*) Bacterial blight (*Xanthomonas oryzae*) Tissue infection (*Cryptostroma corticale*) Brown spot (*Cochliobolus miyabeanus*)	Chakraborty et al. (2000); Rosenzweig et al. (2001); Gregory et al. (2009); Gautam et al. (2013)
Wheat	Common bunt (*Tilletia caries*) Karnal bunt (*Tilletia indica*) Leaf rust (*Puccinia recondita*) Head blight (*Fusarium* sp.) Needle blight (*Dothistroma septosporum, Phaeosphaeria nodorum, Mycosphaerella Graminicola*)	Garrett et al. (2006); Shaw et al. (2008); Gautam et al. (2013); Paterson et al. (2013)
Maize	Tar spot complex (*Phyllachora maydis, Monographella maydis*) Gray leaf spot (*Cercospora zeae-maydis, Cercospora Zeina*) Corn borer (*Ostrinia nubilalis*) Grayish black rot (*Helminthosporium maydis*)	Rosenzweig et al. (2001); Crous et al. (2006); Cairns et al. (2012); Beresford and McKay (2012)
Fruits and vegetables	Downy mildew on grapevine (*Plasmopara viticola*) Black sigatoka in banana (*Mycosphaerella fijiensis*) Potato late blight (*Phytophthora infestans*) Stem or white rot (*Sclerotinia sclerotiorum*) Banana wilt (*Xanthomonas* sp.) Kiwifruit Bacterial canker (*Pseudomonas syringae*) Apple black spot (*Venturia inaequalis*) Onion downy mildew (*Peronospora destructor*) Panama disease in banana (*Fusarium oxysporum*) Pineapple disease (*Fusarium subglutinans*) Potato leafhopper (*Empoasca fabae*)	Evans et al. (2008); Gautam et al. (2013); Beresford and McKay (2012); Paterson et al. (2013)
Fish-food	Dermo disease (*Perkinsus marinus*) Ichthyophonus epizootics (*Ichthyophonus hoferi*) Vibrio illnesses (*Vibrio parahaemolyticus*) Fish pox (*Acroporid serratiosis*) Grass carp haemorrhagic disease (Grass carp reovirus) Apicomplexa infections	Farrell (2002); Riegl (2002); Pikarsky et al. (2004); Burge et al. (2014)

maturity and absolute sterility (Endo et al., 2009). Thorough evaluation of the studies suggest that rice vulnerability to the changing climate is more towards physiological impacts and this crop seems much prone to warming conditions specially due to abrupt rainfall patterns during various growth stages.

2.1.3. Impacts on maize

Maize (*Zea mays* L.) is one of the prime starch resource and accounts for the majority (80%) of the global market share and is produced on nearly 100 million hectares mostly in the lower middle income developing countries (FAOSTAT, 2010). Demand for maize will double by 2050 and it is predicted to become the crop with the greatest production globally by 2025 (Rosegrant et al., 2001). A recent investigation of more than 20,000 historical maize trial yields in Africa showed that for every degree above 30 °C, the grain yield of maize was reduced by 1–1.7% under optimal rain fed and drought conditions (Lobell et al., 2011). It has been reported that the increasing temperatures combined with decreasing precipitation may have major implications for maize production negatively affecting all stages of maize growth and production, particularly the reproductive stage, is most sensitive to drought stress (Çakir, 2004; Wang et al., 2011; Cairns et al., 2012). Furthermore, different plant tissues of maize, organs and developmental stages are affected by heat stress in different ways, depending on the susceptibility of the dominant metabolic processes that are active at the time of stress (Monjardino et al., 2005). There are various abiotic and biotic effects of climate change on maize, such as effects on low soil fertility, pests and disease and drought affecting global maize production (Oseni and Masarirambi, 2011). Acute high temperatures can also induce shortened life cycle, reduced light interception and increased sterility, reduced growing season and shortened grain-filling period (Wang et al., 2011). The growing temperature higher than 32 °C results in loss of grain yield especially in tropical and moderate zones and an increase of 2 °C can cause more than 10% yield loss in maize (Jones and Thornton, 2003; Cairns et al., 2012). While the yield is expected to decline in some parts of the world but it may increase in some other parts where maize is not currently grown as the main crop (Wang et al., 2011; Table 2). This indicates that changing temperatures may lead to the shifting of crop cultivation areas to new areas and consequently making more ecological struggle and adaptation responses for this crop.

Some sensitivity experiments illustrate the effects of shifts in sowing dates on maize yield under diverse climate-change conditions and report huge declination in the yield (Williams, 2006). Elevated temperature has also been found to negatively affect protein synthesis at the seedling and vegetative stages of maize crop (Cairns et al., 2012). The growth and senescence of phytomers and the role of the phyllochron and phytomer formation during developmental stage is drastically affected by temperature stress in maize (McMaster, 2005). Various other significant physiological changes have been reported such as, changes in carbon utilization and partitioning and decrease in maize leaf elongation rate, leaf area, shoot biomass and photosynthetic CO_2 assimilation rate (Monjardino et al., 2005; Potters et al., 2009).

Reproductive processes in maize are also on the verge of danger. High temperature results in an increase in the number of antipodal cells in the maize embryo sac and causes asynchrony in the tasselling and silking of maize, whilst the growth and receptivity of the style is also inhibited (Ribaut et al., 2009). Effects of heat stress are severe as they decrease maize grain yield and change starch quality by decreasing starch granule size, amylose content and short branch-chains and increasing gelatinization temperature (Wang et al., 2011). It has been found that constant occurrence of high temperature during grain filling in maize reduces the granule size (Lindeboom et al., 2004). These kinds of susceptibilities of maize to high temperatures and drought stress are generally attributed to its separation of male and female flowers where female tissues are most susceptible (Jablonski et al., 2007). Increased flowering synchrony and delayed leaf senescence were also reported during high temperatures and drought conditions (Hedhly et al., 2009). Higher temperature induced heat stress may affect number of grains and weight and size of kernel and it decreases the number of fertilized ovules which develop into grain (Efeoğlu et al., 2009). It reduces fertilization, viability and in vitro germination of pollen, pollen water potential, quantity of the pollen shed and pollen tube germination (Barnabás et al., 2008; Lu et al., 2014). Consequently, probability of pollen damage increases due to heat stress reducing sink capacity (Lu et al., 2014), affecting cell division, sugar metabolism and starch biosynthesis, (Cicchino et al., 2013).

It is noteworthy that the variety and receptiveness of agricultural pests and diseases in maize crop will vary under changing climates. Modified host physiology and resistance are the featured effects of climate change on maize and it has the potential to alter the stages of pathogen development (Rosenzweig et al., 2001). As various environmental conditions such as, rainfall, relative humidity, temperature and sunlight control disease development; any change in them is likely to have an effect on the diseases prevalence and emergence in maize (FAO, 2008). For example, *Cercospora zeaemaydis* and *Cercospora zeina* causing gray leaf spot (GLS) in maize and corn root worm (*Diabrotica*) are highly sensitive to environmental conditions (Crous et al., 2006; Table 2). The climate change driven expansion of maize production will make new areas susceptible to ingress, establishment and spread of diseases (FAO, 2008). Some characteristic diseases interrelated with climate change are given here for the food sources selected in this synthesis which gives an account of spreading danger of climate change triggered disease occurrence to these crops (Table 2).

2.2. Impacts on fruit and vegetable crops

There are growing demands for the fresh fruits and vegetables all over the world and exports for which throughout the world has been increasing day by day (FAOSTAT, 2010). There are evidences of variations in climate, between years and regions which can have a strong effect on horticultural production worldwide. A warmer climate is supposed to be favorable for subtropical fruit production but at the same time can also be harmful for some temperate fruits (Luedeling, 2012; Kuden, 2013). Although, there is possibility of increase in yields of fruits and vegetables due to more carbon dioxide available for growth, but this may be limited by the less availability of water and nutrients (FAO, 2008). The increased risk of spring frost, new or more aggressive diseases and pests, hail and water shortage or more variable rainfall with longer droughts are some of the major factors highly detrimental for fruit crops (Chmielewski et al., 2004; Braun and Markus, 2012). The vast amount of research has been carried out on the reproductive stage effects of changing climate in fruits and vegetables and the flowering and its conversion into fruits is the major phenomena which is directly impacted by the climate change (Braun and Markus, 2012). Flowering and flower development are the major physiological phenomenon in fruits where most of the studies are concentrated to understand the impacts of varying temperatures (Ruiz et al., 2007). Flower at a dissimilar time from their pollinator, developments of ‘blind buds’ failing to develop in spring, pollination problems due to sporadic flowering and poor leaf quality at flowering time will lead to poor fruit set in fruit crops worldwide (Yamane et al., 2006; Campoy et al., 2010). ‘Initial flowering’ or ‘too early flowering’ and ‘full flowering’ are the significant phenological stages which are known to be affected by changing climates over the years (Rodrigo and Herrero, 2002; Ashebir et al., 2010). Reports show the impact of climate change on decreasing firmness with increasing temperature and on mean number of flowers per winter bud (Legave et al., 2009). Dormancy and meristem inactivity are also induced in some unfavorable environmental conditions, such as chilling temperatures or short photoperiod; and effects of pre blossom temperatures have been reported on fruit set and flower development (Rodrigo and Herrero, 2002; Campoy et al., 2011). For example, blossoming of fruit trees in Germany have advanced by several days and general growing season in Europe and Germany has been extended by 10 days during the last decades (Chmielewski et al., 2004). Because of this, risk of late frost damages and the number of pest populations in orchards has risen (FAO, 2008). Earlier spring growth and longer-milder autumns will extend the growing season but, untimely and early flowering may be vulnerable to spring frosts (Seki et al., 2003). All these environmental stresses can affect developmental changes in the anthers, irregularities in the epidermis and endothesium, lack of opening of the stromium, and poor pollen formation leading to reduction in post harvest quality and quantity of fruits and vegetables (Moretti et al., 2010; Luedeling, 2012). Bud drop, irregular and atypical flower development, dehiscence and poor ovule viability, reduced carbohydrate availability and other reproductive abnormalities occurring due to high temperatures have also been reported (Hazra et al., 2007; Hedhly et al., 2009).

Physiological effects of climate change on photosynthesis, respiration, aqueous relations in cells and membrane stability during growth and development of fruit and vegetable crops have been documented (Collier et al., 2014). The elevated temperatures will also reduce or inhibit plant hormones, primary and secondary metabolites, and seed germination depending on the species and level of stress (Kuden, 2013). Coloring disorder, enhancement as well as reduction of fruit softening and spoiling acids have also been reported (Sugiura and Yokozawa, 2004). High temperature associated limited soil moistures are the key causes of low yields in vegetables in the tropics which will be aggravated day by day (de la Peña and Hughes, 2007). Increasing temperature will reduced the irrigation water availability, decrease soil fertility, increase soil erosion and flooding and salinity incursion; which are major restrictive factors in sustainable vegetable production (Wheeler and von Braun, 2013; Anwar et al., 2015). Salinity causes ion-specific stresses reflected in wilting, loss of turgor, leaf curling and epinasty, leaf abscission, decreased photosynthesis, respiratory changes, loss of cellular integrity and tissue necrosis which may prove fatal for the vegetable plants (Walker et al., 2003; Miller et al., 2010). Climatic change induced UV effects have shown production of anthocynin and some genetic effects which are posing threats on genetic makeup of the vegetable crops meanwhile exact evidences of the impacts of climate change on gene levels of vegetable crops are very few (Yunxia and Michael, 2011).

The worldwide variability in yield of selected food crops since 1961–2012 (viz. wheat, rice, maize, fruits and vegetables) has been shown in Fig. 1(B) indicating departures from mean yield with respect to their minimum and maximum yield. Whereas, diagrammatic representation of some major impacts of increasing CO_2 and temperature on major food sources selected in this synthesis has been represented in Fig. 2 depicting some major impacts of climate change on different parts of the crop plants and also represents an overview of heat stress response mechanism in these crops.

2.3. Impacts on fish-food (fishes and catch fisheries)

As a major food source; fisheries from the world's lakes, rivers and oceans offer key sustenance for many poor communities, in many parts of the world. It is not just a vital food option but also a very important source for work and money for millions of people around the globe (FAO, 2008; Allison et al., 2009). Hence, fish-food becomes an important and integral part of the climate change impact studies on the food security being one of the chief animal food sources in the world. The world's population is expanding and total supply and consumption of the fish food has been growing at a rate of 3.6% per year since 1961. The 13.8–16.5% animal protein demand of humans has been met by fishes, crustaceans and molluscs and the average apparent per capita fish food consumption has increased from 9 kg to 16 kg since 1961. The per capita availability of fish and fish products has nearly doubled in last 40 years (FAO, 2008). Moreover, currently two-thirds of the total fish food supply is obtained from capture fisheries in marine and inland waters, while remaining one third is only derived from aquaculture. Since, the yields from the catch fisheries are now stagnant and somewhat decreasing due to many stresses; climate change is one of the strongest factors in them causing disturbances in growth and development conditions of fishes and fisheries (Jennings and Brander, 2010; Holbrook and Johnsan, 2014). Thus it becomes important to understand the climate change impacts on fish food also when we deal with the food security prospects of the world under climate change.

There are various potential effects of elevated temperature and distorted nutrient quality of resources on metabolic, foraging and stoichiometric characteristics in fresh water and marine fishes (Woodward et al., 2010; William et al., 2013). Various studies on the physiology, metabolism and reproductive biology of fishes suggest that changes in pH and CO_2 can have remarkable consequences on egg fertilization and survival of early developmental phases (Ishimatsu et al., 2005; Pörtner and Peck, 2010; Fig. 3). Increase in temperature has been found to effect estrogens

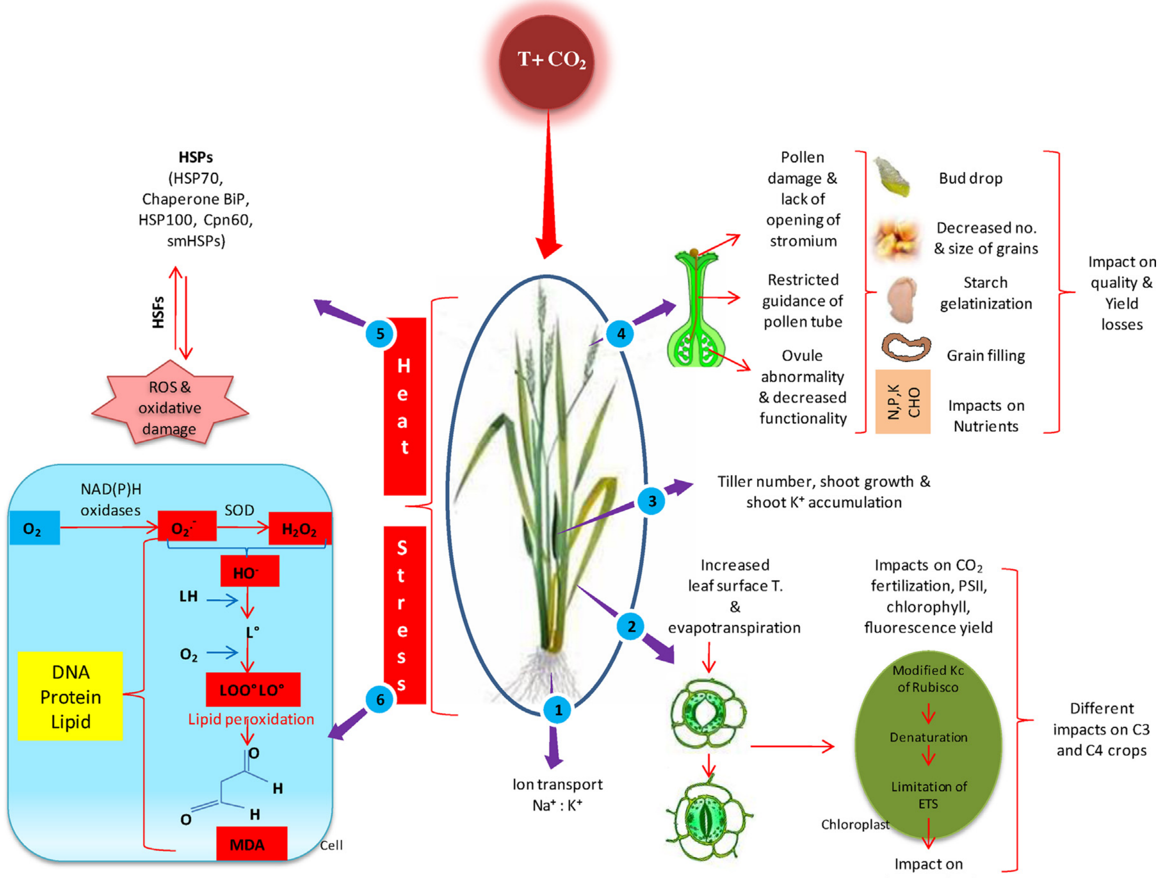

Fig. 2. Schematic of some major impacts of climate change on major food sources selected in this synthesis (excluding impacts on fisheries). Some characteristic responses of wheat, rice, maize, fruit and vegetable crops to changing climate are: (1) Some major impacts on root zone ion transport system from roots to the plants creating ion imbalance causing various physiological stress and effects. (2) Increased leaf surface temperature and related evapotranspiration leads to increased closure of leaf stomata and also cause various changes in photosynthesis and its related phenomenon in chloroplasts due to the impacts on Rubisco and ETS limitation. (3) Tillering may decrease and impacts on shoot growth may occur due to reduced shoot K^+ accumulation. (4) Detrimental impacts on pre and post fertilization processes as they directly affect both yield quantity and quality by disturbing different stages of flowering and grain formation and inducing sterility. (5 and 6) Heat stress induced due to the climate warming triggers the production of HSPs and also produces oxidative damage through the production of ROS. Plant cells sense ROS via HSFs; which in turn activate HSPs expression for plant defense. ROS damage DNA, protein and lipids of plant cells and may prove lethal.

Abbreviations: T, temperature; ROS, reactive oxygen species; SOD, super oxide dismutase; HSPs, heat shock proteins, HSFs, heat shock transcription factors; MDA, malonaldehyde.

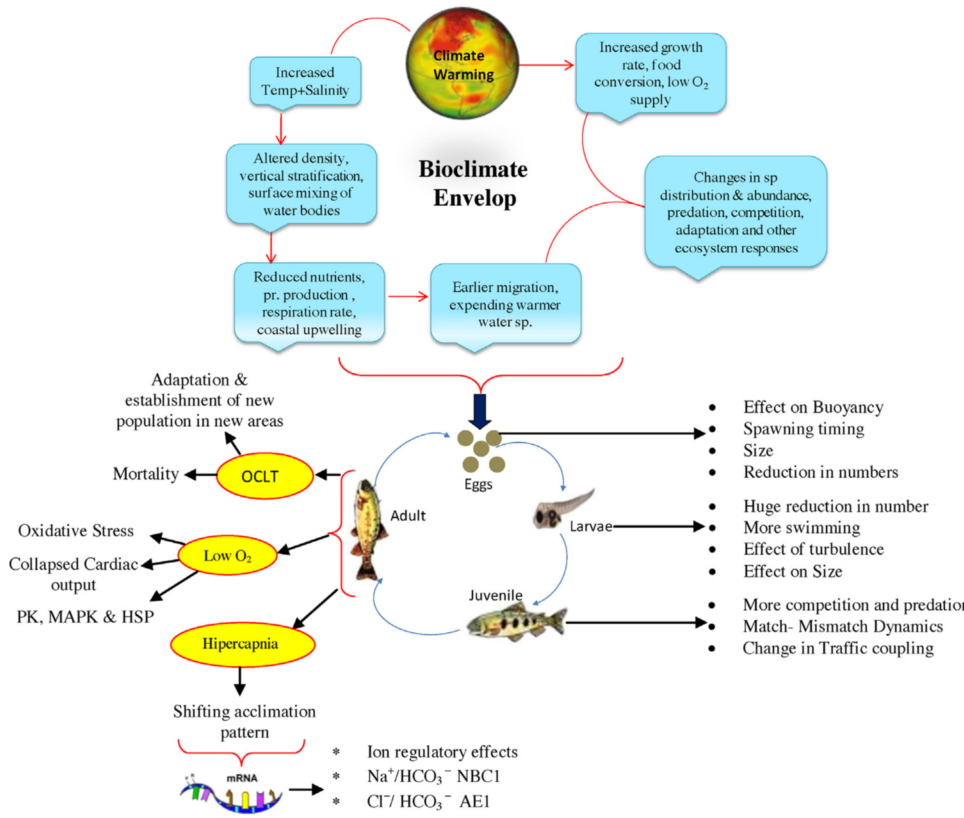

Fig. 3. Schematic of some major impacts of climate change on fishes and fisheries in the world. The climate warming causes a characteristic "Bioclimatic envelop" by impacting different levels of the habitat organization and ecosystem in water bodies which affects the whole life cycle of a fish. There are characteristic impacts on different stages of the fish life. Low dissolved O_2 in waters due to increased temperature and high CO_2 (hypercapnia) both have lethal effects on various bio-physicochemical processes of a fish which in turn may lead to extinction of valuable species.
Abbreviations: OCLT, oxygen and capacity limited thermal tolerance; PK, protein kinase; MAPK, mitogen-activated protein kinases; HSP, heat shock proteins; NBC1 & AE1- RNA types.

in fishes (Brian et al., 2008). With increase in temperature metabolic demands will rise and per capita BMR will also increase and in such cases of individual metabolic rates rise, warming will decrease the total biomass of the fresh water fishes (Pörtner and Peck, 2010; Yvon-Durocher et al., 2010; Lefort et al., 2015). Warming induces ephemeral changes in body size affecting large and rare species occupying high niche in the food web are prone to lost first (Harborne, 2013). Furthermore, warming could arouse productivity, allowing food chains to grow longer and the size spectrum to broaden (Milner et al., 2009). Ethological or behavioral responses to environmental changes may induce many effects in fish stocks. For example, temperate fish stocks are likely to change due to the direct effects of exposure to increasing ocean temperature; affecting species indirectly through pole ward movement (Koehn et al., 2011; Kerosky et al., 2012; Cheung et al., 2013), habitat changes and increasing disease outbreaks (Pörtner and Peck, 2010). Strong evidences of climate-related impacts on species distributions and distributional shifts of fishes are related with the warming of the temperate oceans; consequently dominance of warm-water species is escalating (Last et al., 2011; Fig. 3). There are reports demonstrating the influence of elevated temperatures on the antiviral and antibacterial immune response in fishes which appears to decrease after prolonged exposures (Dang et al., 2012). Thermally susceptible species are narrowing to smaller ranges due to climatic changes affecting availability and distribution of some important fishes which affects fisheries and economies both (Perry et al., 2005).

Warming increases heart rate and velocity of cardiac contraction with depressed forces of contraction in fishes while some species show enormous physiological flexibility and can compensate the effects of temperature (Kirby et al., 2009; Franklin et al., 2013). Augmented stratification in lakes and rivers have been reported due to higher inland water temperatures reducing mixing of water, primary productivity and ultimately food supplies for fishes and thus food availability for larval and juvenile fishes causes additional damage to fisheries (Barange et al., 2014; Brander, 2015). Flooding episodes also introduce disease or predators into aquaculture facilities harming fisheries in a great deal (Allison et al., 2009; Table 2). As far as the effects on the phenological changes in fishes are concerned shifts in the seasonal timing of crucial events, such as spawning, have been analyzed and reported (Lefort et al., 2015). An increase in juvenile growth and temperature may result in a decrease in the length and age of fishes at first maturation, affecting the growth of adults (Edwards and Richardson, 2004). Changes in cap compositions of climate sensitive fishes, reduced catch rates, altered seasonality, reduced fishing days, altered recruitment patterns and recruitment success and earlier age maturity and mortality are some of the major impacts of changes in temperature and other climatic factors (Wilson et al., 2010).

Due to more frequent harmful algal blooms produced due to increase in sea surface temperature; the problems such as dissolved oxygen stress conditions, incidence of disease, parasites, competitors, predators and invasive species occur which harm fish populations (Johann et al., 2013; Table 2). Changes in climate have also affected the timing and success of fish migrations, peak abundance, as well as sex ratios while rising sea level pose vigorous challenges to fisheries by loss of land and changes to the estuary systems (Attrill and Power, 2002). There are not only negative impacts of climatic changes on fisheries; as the retreat of glaciers can also create new habitats for some freshwater species (Milner et al., 2009). However, many other species will be unable to adapt these new habitats (Milner et al., 2009). Schematic of some major impacts of increasing CO_2 and temperature on fishes and fisheries in the world has been given in Fig. 3 showing characteristic impacts of climate change on different stages of the life cycle of the fishes.

In summary, the response of fish populations to climate change will vary between species. The variation is supposed to be interrelated with their adaptations to the shifting and changing environmental settings in their particular habitats. In response to these changes many fish species are expected to move back into deeper-cooler waters while species with spatially limited habitat requirements will be more sensitive to climate change than those without specific habitat requirements (Rijnsdorp et al., 2009).

3. Climate change induced stress responses

Temperature stress produces detrimental effects on plant and animal metabolism through disordered cellular homeostasis, and extricated physiology in plants (Seiler et al., 2011). Largely the induction of heat-shock protein (HSP) synthesis induces thermotolerance (Suzuki and Mittler, 2006). Stress-induced cellular changes bring enhanced buildup of toxic compounds such as reactive oxygen species (ROS; e.g. superoxide; (O_2^-) produced by NADPH oxidases, $^1O_2$, H_2O_2, and $HO^\bullet$) which are toxic molecules able to cause oxidative damage to proteins, DNA, and lipids and generally produced in chloroplasts, mitochondria, and peroxisomes (Apel and Hirt, 2004; Fig. 2). The ROS may also exert stress-induced damage at the cellular level through peroxidation of lipid membranes in cereals (e.g. wheat) and may also induce oxidative stress in fishes by enhancing malondialdehyde (MDA) content (Király and Czövek, 2002; Savicka and Škute, 2010). It has been revealed that plant hormones such as salycylic acid (SA), abscisic acid (ABA) and ethylene play significant role in mediating ROS and temperature stress signals (Overmyer et al., 2003). Reducing the rate of ROS production in cells is imperative and may be achieved by adjustments to cellular metabolism or by controlling the accumulation of particular compounds with a high redox potential in the cells (Suzuki and Mittler, 2006). To completely understand how plants survive with the stresses produced by the climate change, future research should include the interrelated mechanisms involved in stress responses and the complex manners by which these mechanisms are synchronized with other physiological and biochemical mechanisms.

4. Summer and winter sensitivities of the crops and their acclimation patters

Sensitivity of the crops towards short term climatic changes is an important parameter to be taken into account while dealing with the impact studies of climate change (Mondal et al., 2014). Any sudden change in normal growing temperatures in summer and winter growing crops may induce many bio-physical alterations (Table 3). Sudden high increase in temperature in summer crops and chilling, freezing and warm conditions during growth of winter crops affect growth and development by upsetting sensitivities of the temperature dependent physiological and biochemical processes (Wheeler et al., 2000; Young et al., 2004). Same crop may show different summer and winter sensitivities and it may also be cultivar specific (Connor et al., 2002). Sensitivity is higher when freezing temperature increases in vulnerable stages of flowering to fruiting (Porter and Gawith, 1999; Taşgín et al., 2003) and when the unusual changes occur in night and day temperatures than normal (Peng et al., 2004). Low temperature (chilling and freezing) injury can occur in all types of crops, but the mechanisms and magnitude of damage vary considerably (Bergqvist et al., 2001; Lurie and Crisosto, 2005). Many fruit, vegetable and ornamental crops of tropical origin experience physiological damages when subjected to temperatures below about +12.5 °C, which is above freezing temperatures and this damage above 0 °C is chilling injury rather than freeze injury (Allen and Ort, 2001; Lurie and Crisosto, 2005). Freeze injury occurs in all plants due to ice formation in cells (Taşgín et al., 2003). Many tropical crop plants often experience severe frost damage when exposed to temperature slightly below zero, whereas colder climate crops habitually survive with little damage if the freeze episode is not too severe (Porter and Gawith, 1999).

Irregular short chilling episodes in many temperate regions are typical where thermophilic crops are grown such as maize in the Midwest USA. These short environmental episodes are much affective for these crops reducing their physiological activities (Badu-Apraku et al., 1983; Perdomo et al., 2014). Weather sensitivity of rice in some tropical/subtropical regions has been reported and is of immense use to understand the sensitivity area and factors (Yan et al., 2006; Okami et al., 2015). The altered climatic factors during these short events affect rice growth and yield, with their relative influence during various rice growth stages (Perdomo et al., 2014). These sensitivity analysis are useful to understand major vulnerable growth stage, and the crucial thresholds of these climatic factors during the most susceptible phases (Peng et al., 2004; Yan et al., 2006; Perdomo et al., 2014). In addition, the phenological calendar of a crop is an important factor being responsible for its sensitivity to climate. For example, frost sensitivity at flowering is usually higher than vegetative stage and can occur in annuals, multi-annuals and perennials crops including fruit trees (Verheul et al., 1996). Frost damage induces radical effect upon the entire plant or its part, reducing yield or affecting quality of the produce (Taşgín et al., 2003). Sunscald injuries, bark splitting, tip dieback, trunks freeze may occur during chilling and freezing conditions, killing xylem cells and filling vessels with gummy occlusions, rotting organisms on which the invade the injured trees and reduce productivity (Wheeler et al., 2000; Lurie and Crisosto, 2005).

Morphological and biochemical acclimatization responses in plants to tolerate these changes have been on the centre of many studies (Shen et al., 2000; Proveniers and van Zanten, 2013). Species or varieties exhibit different frost damage at the same temperature and phenological stage, depending on existed weather conditions, and they may response via “hardening” (Taşgín et al., 2003). Morphologically plants acclimatize via different leaf and surface changes (Aroca et al., 2003; Okami et al., 2015). At biochemical levels, different components of polyamines are largely involved in acclimation patterns by modulating many plant growth factors and processes related with enzymatic and hormonal regulation of plant growth and developments (Lee et al., 1997; Shen et al., 2000; Yang et al., 2007). Involvement of heat shock proteins in acclimation patterns in fishes has also been documented in studies (Dietz and Somero, 1992; Pörtner and Knust, 2007). All these biochemical changes play an important role in modulating many bio-physiological control systems of the plants and fishes and induce summer or winter acclimation towards the micro/macroclimatic changes (Alcázar et al., 2011; Proveniers and van Zanten, 2013; Perdomo et al., 2014). In the present synthesis some important susceptible growth phases and processes have been identified for all selected food sources to differentiate and understand the weather related

Table 3
Sensitivity responses (summer and winter) of the selected food sources and their morphological and biochemical acclimation patterns.

Food sources	Summer sensitivity	Winter sensitivity			Acclimation response		Reference
		High temperature	Chilling	Freezing	Biochemical	Morphological	
Wheat		Delayed vernalization, affects early initiation of spikelet primordia, pollen sterility at anthesis, increase in grain dry weight. Both temperature sensitivity and growth rates vary between cultivars during grain-filling. Reduced numbers of developing grains in short period of hot temperature in winter cultivars	Cold stabilities of activated oxygen-scavenging enzymes are affected. Rapid reduction of leaf temperature induces short term soluble carbohydrates accumulation	Modulation of the stable quinone receptor and non photochemical quenching in PSII. More accumulation of soluble carbohydrates suppresses photosynthesis by reducing Pi cycling and depleting ATP levels in chloroplast.	Polyamines are largely involved, e.g.: Putrescine, mediates abscisic acid's effects in acclimation. Cultiver specific acclimation: putrescine and free spermides increases in winter wheat while putrescine decreases in spring wheat. Salicylic acid can increase freezing tolerance in winter wheat leaves by affecting apoplastic proteins.	Acclimation through increased leaf mass per unit area, biomass allocation and early vigor. Decrease in the evaporative surface of the leaves.	Porter and Gawith (1999); Wheeler et al. (2000); Taşgín et al. (2003); Young et al. (2004); Ludwig and Asseng (2010); Alcázar et al. (2011); Mondal et al. (2014); Perdomo et al. (2014)
Rice	Daytime (max) temperature induces shortening of growing periods and yield reduction. Decreased yields under increased night-time temperature associated with global warming.		Experimental chilling Effects on stress phenotypes of rolling leaves. Increased relative electrolyte leakage. Decreased net photosynthetic rate.	Temporal changes of total proteins.	Higher levels of putrescine, free spermides, and spermine induce acclimation to water stress. Increased arginine decarboxylase during chilling acclimation.	Changes through aberrant cell morphology and depolymerized and dispersed microtubules. Increase in tiller and panicle number and size. Increased leaf area index.	Lee et al. (1997); Peng et al. (2004); Yan et al. (2006); Alcázar et al. (2011); Okami et al. (2015)
Maize	Very high temperature decreases the duration of growth and grain yield. Decreased rate of leaf appearance. Earlier flowering.	Higher night temperatures may result in an increased proportion of grain weight in kernel resulting from remobilization of stored dry matter.	Disruption in thylakoid electron transport. Disrupted carbon reduction cycle and stomatal control. Decrease in the rate of leaf appearances and net assimilation rate.	Changes in leaf appearance rate, leaf area partitioning, and specific leaf area.	Involvement of abscisic acid in avoiding chilling effects and water stress. Increase in putrescine, Salicylic acid in the aerial portions due to activated glutathione reductase. Increase in 1-aminocyclopropane-1-carboxylic acid during acclimation.	Phenotypic plasticity, with increased leaf mass per unit area, and clover development. Various changes in leaf morphology.	Badu-Apraku et al. (1983); Verheul et al. (1996); Allen and Ort (2001); Aroca et al. (2003); Alcázar et al. (2011)
Fruits & vegetables	Impact on pollen germination and tube growth. Increase in anthocynin and total phenolic contents in fruits.	Reduction in micro and mega gametophyte fertility. Induces fruit abortion. Disrupted seed production during high temperature events.	Surface pitting, necrotic areas and external discoloration. Disruption in thylakoid electron transport. Chill induced water loss. Cultivar dependent responses of antioxidant activity. Increased total phenolic content and anthocyanin. Mealiness or woolliness. Internal browning or reddening of fruits. Ion imbalance and leakage.	Intra/extra-cellular freezing can mechanically disrupt the protoplasmic structure and other cells. Changes in membrane lipid fluidity. Winterkill of buds and bark tissues. Flower style is more sensitive than the ovary to frost damage.	Free spermides facilitate chilling tolerance in some vegetables through prevention of chill-induced activation of NADPH oxidases in microsomes. Putrescine decreases cold induced electrolyte leakage. Spermine increases chilling tolerance of the photosynthetic apparatus. Increase in spermine is also related to freezing acclimation in some fruits.	Phytochrome interaction factor mediated morphological acclimation in flowering stages via auxin stimulation. Thicker leaves with greater no of palisade cell layers.	Lyons (1973); Bergqvist et al. (2001); Shen et al. (2000); Connor et al. (2002); Lurie and Crisosto (2005); Alcázar et al. (2011); Dumlao et al. (2012); Proveniers and van Zanten (2013)

Table 3 (*Continued*)

Food sources	Summer sensitivity	Winter sensitivity			Acclimation response		Reference
		High temperature	Chilling	Freezing	Biochemical	Morphological	
Fish food	Altered Match–Mismatch dynamics. Mismatch between demands for oxygen and oxygen supply capacity to tissues restrict tolerance to thermal extremes.	Continued shifts in distribution. Alterations in community interactions. Metabolic trade-offs and growth reductions.	Live-chilling significantly affects rigor mortis, pH and muscle glycogen. Super-chilling may result in higher liquid leakage.	Muscle metabolic changes. Increased myofibre breakages.	Higher levels of heat shock proteins (HSP90) in brain tissue in Summer-acclimatized fishes than winter-acclimatized ones. Homeostatic behavioural responses during acclimatization of winter chills may reduce resting oxygen consumption.	Some changes in body structure to enhance swimming performances. Development of oxygen consumption restricting morphology such as alteration in gill structures.	Dietz and Somero (1992); Heggenes et al. (1993); Skjervold et al. (2001); Perry et al. (2005); Pörtner and Knust (2007); Bahuaud et al. (2008); Bowden et al. (2014)

growth and development of the major food sources of the world (Table 3).

5. Combating climate change impacts: agricultural adaptation and mitigation strategies

There are varied risks of climate change and thus there is a strong need for successful adaptation and mitigation strategies across different scales and dimensions of impacts depending upon crops and region (Table 4). The important risks of increasing warming of globe are variable and untimely rainfall events, unstable winter seasons, more disease occurrences and crop failures (Adger et al., 2005). However, many research outputs indicate that prolonged short growth season collectively with higher growth temperatures can provide new opportunities for agriculture in many agrological zones (Uleberg et al., 2014). These climate change impacts on agricultural outputs in different continents are expected to differ and hence require customized adaptive strategies (Tscharntke et al., 2012; Uleberg et al., 2014). These strategies should include those factors which affect agriculture in a great deal such as land use and soil properties, local climate, local and regional market forces, agriculture management strategies and agricultural tradition composed of coherent traditional wisdom and agricultural practices (Reidsma et al., 2010; Tripathi and Singh, 2013). To take some of the advantages of the current climate change, adaptation and mitigation strategies should consist of cautious crop and cultivar selection, proper selection of sowing and fertilization time corresponding to the selected food sources (Cairns et al., 2012). Judicious economic investments in the agricultural systems to cope with any uncertainty are also much important for adaptive capacity building of any country (Cartwright et al., 2013). Research programmes to find out genetically uniform, high yielding cultivars, higher production potential, particularly for annual plants and drought or water logging resistant varieties are also on the greater need (Civantos et al., 2012; Adger et al., 2005). There are many other important adaptive strategies which should be adopted in agricultural practices to cope up with adversities of climate change and these warrant extensive collaborative use of farmer's perception with regional climate-crop models to insure the necessity and sustainability of the adopted practices to avoid any mal-adaptation. Table 4 illustrates various important adaptive/mitigative strategies for sustaining agricultural production worldwide which should be implemented by improved sustainable agricultural policies of different countries.

6. Conclusion and future approaches

To summarize, it can be stated that world's food security is in immense pressure under climate change and much complex to understand due to interactions involved at every stages of the life cycle of a food source. Climate change; is unswervingly influencing the human survival through its agricultural impacts by higher temperatures, droughts, shifts in cropping areas, floods, soil erosion, and rainfall variations affecting the food security of the globe. Reduced quality and quantity of major food sources due to climate change are the basic effects through which world is confronting. In present assessment, investigating various scales and dimensions of the impacts of the climate change on major food sources of the world; we find that all selected major food sources of the world are facing huge impacts on various facets of their life cycle and are going through physiological, biochemical, phenological and genetic changes as well. Crop sensitivities differ in different seasons and are cultivar specific while acclimation responses have various morpho-biochemical patterns to understand. While wheat and rice crops are sustaining under elevated

Table 4
Integration of different adaptation/mitigation strategies and their potential positive impacts to cope up with future and current climate change impacts to selected food sources.

S. No.	Adaptation/mitigation strategies	Possible positive impacts	References
1	Improved forecasting of weather and related phenomena and easy access of these to local farmers	This will induce adaptive capacities to change the sowing and harvesting timing of crops during reduced winters and untimely rainfall events over a long time assessment	Qiao et al. (2014)
2	Crop rotation and intercropping, and introducing legumes	This practice should employ as an efficient measure to maintain good soil properties thus adapting towards ill effects of increasing temperatures on soil bio-physical properties and to improve N-use efficiency of the soils	Adger et al. (2005)
3	Enhancing organic farming to reduce chemical intensive agricultural practices	Increased productivity due to higher temperatures may demand more use of fertilizers, hence not good for new areas. Thus new adaptation in the form of organic farming may enhance new possibilities of agricultural production and also enhance top soil carbon sequestration	Tuomisto et al. (2012)
4	Understanding people perception and responses and exchanging experience and knowledge among farmers and other agriculture dependent communities	This will serve as advisory inputs and will increase the adaptability to different challenges and opportunities in different regions. This may give far reaching inputs to include in sustainable agricultural policies and programmes	Tripathi and Singh (2013)
5	Shifting and adjusting the timing of different farm operations and cultivation practices	This seems little bit difficult but by adapting to changes in the onset of rainfall and temperature changes a continuous adjustment may take place over time along with the gradually changing climate.	Cairns et al. (2012)
6	To search and introduce significant ecological alternatives to the use of pesticides	This will prevent soil damage and thus will be a positive input against soil damaging properties of climate change	Civantos et al. (2012)
7	Increasing biodiversity in agro-ecological zones	Biodiversity has strong role to play for agricultural productions since more species-richness and rich biodiversity contribute to yield benefits by more pollination opportunities, weed suppression and persistency	Tscharntke et al. (2012)
8	Involving plants protection techniques and tools	This will reduce the damage and yield losses of crops under any uncertain climatic events	Seki et al. (2003)
9	Improvement of drainage systems	To ameliorate the plausible impacts of high rainfall events during shorter growth periods, drainage system should be effectively made and maintained. In this way this adversity may be compensated by channelling the excess water in water deficit areas. This is an important aspect for adaptation toward flood risks in flood prone areas	Krishnan et al. (2007)
10	Tillage, land allocation and land improvement	Low tillage or no tillage practices, proper land allocation for specific crops and land improvements will induce soil and water conservation and weed control thus are adaptive for the warming conditions and soil moisture loss	Reidsma et al. (2010)
11	Efficient irrigation measures	Various technological improvements in irrigation practices such as drip and sprinkle irrigation are important to reduce the water loss and to maintain soil moisture as needed by some specific crops.	Elliott et al. (2014)
12	Employing new economic measures: insurance and reinsurance, and resource based livelihood options and market availability	Climate insurance is the very important sector to utilize the potentials of growing market forces in globalized world. This will encourage the farmers to use adaptive measures.	Cartwright et al. (2013)
13	Research and development	Introducing genetically engineered drought and flood resistant crop varieties and high yielding varieties for low production areas to adapt with the climatic aberrations in different regions of the world	Uleberg et al. (2014)

CO_2 levels in many wheat growing areas of the world but the impacts of increasing temperatures and its interactions with various physio-biochemical processes are much diverse so that they negate some beneficial impacts. Shifting of cropping areas is one of the major factors which are beneficial and harmful at the same time for all food sources. Much varied and detrimental impacts are seen on maize crop in current climatic trends as compared to wheat and rice. Fruits and vegetable production is under immense stress due to huge vulnerabilities of their reproductive stages for increasing temperature and also due to insect-pest attacks and disease prevalence. The fish-food as the critical animal food source is also facing gregarious impacts of changing climate shown through alteration in their habitat requirements and adjustments to their changing environmental conditions and is on the verge of extreme danger.

By this assessment an absolute illustration can be obtained about the various experimentally proved and observed impacts of the climate change on major food sources to summarize the scales and dimensions of the impacts and to understand that how the changes will lead the world; and how it should be abandoned to enhance food security of the world. Researches should focus more on summer and winter sensitivity differences and cultivar specific research priorities should be fixed to utilize more tolerant and adaptive crop and fish species. Researches on biochemical acclimation responses are now growing and future researches should focus to enhance the acclimation patterns in the susceptible crops. More concerns are needed and sectoral and impact specific plans should be made to avoid any unfavorable situation for food security. Hence, a collective effort is warranted to employ various adaptive and mitigative strategies including research and development activities suitable for crop types, regions and specific problems to cope up effectively with climate change impacts.

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