Agric Res (March 2015) 4(1):21–30
DOI 10.1007/s40003-015-0152-z

REVIEW

Climate Change and its Implications on Stored Food Grains

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Received: 5 March 2014 / Accepted: 22 January 2015 / Published online: 28 February 2015

Abstract Among the risks that the changing climate trends pose to various sectors, the effect of climate change on grain storage is an overlooked concept. The paper reviews the effect of climate change on the major components of stored-grain ecosystems and the system as a whole. In general, the effects of climate change on the quality of stored grain can be considered direct or indirect. Direct effects include role of climate change on the growth and developmental cycles of biotic components such as insect pests and indirect effects include the effect of rising global temperatures on grain drying conditions and other post-harvest unit operations that would ultimately affect stored grain quality. The effects on stored grains forecasted in both tropical and temperate regions of the world are summarised. The importance of mathematical modelling and the directions for research that can mitigate the effects of global climate change on stored food grain are also highlighted.

Keywords Climate change · Grain storage · Biotic and abiotic factors · Mathematical modeling · Mitigate

Introduction

Global Climate Change

The present global scenario explains convincingly that climate is changing. Global temperature has increased by > 0.5 °C in the past century [37] and the Intergovernmental Panel on Climate Change envisages an increase in global mean temperatures of 1.1–5.4 °C by 2100 [8]. In the past, the effects of climate change were projected in connection with alterations in land and in the evolution of different forms of life. Although there are other contributing factors, of late climate change is related to global warming as the outcome of human activities. Changing weather patterns, drastic melting of polar icecaps and the rising sea levels observed over the past decades are among the most threatening effects of climate change. As a growing concern, prediction of climate change and its effects have demanded attention in several global Summits. Changing climate trends have also shown direct and indirect relationships to agriculture [21] and global food production [43]. The climate change will have significant effects on plant growth, crop productivity and global food supply trends [54]; hence will be a dominant threat to world food security. In recent years, droughts and other harsh weather events explained as a result of the changing climate trends are becoming common. Numerous mitigation strategies are being developed to handle the crisis [50]. Safe food grain storages by themselves are considered as a measure to adapt to the changing global climates [73] and as a channel to food security [38], particularly in periods when agriculture fails. However, this paper presents that grain storage itself can be heavily affected by climate change; an overlooked concept of stored grain ecosystems.

Grain Storage Ecosystems

Grain may be stored at different levels in the food supply chain: the farmer, the miller, the importer and the

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government—all have different motives to store grain. The principal purpose is to meet consumer demands for food grains. Food grains may be stored in silos, warehouses, bags, containers, traditional storage structures, or in other defined units. Stored grain is a man-made ecosystem undergoing incessant interactions between several abiotic (for example temperature, relative humidity, inter-granular CO_2 levels and moisture content) and biotic factors (such as insect pests, fungi, mites and rodents). Continuous interactions occur with time and unfavourable interactions cause grain deterioration. Figure 1 shows the various biotic and abiotic factors associated with stored grains. Particularly for long-term storage, to have a strong control over these factors, optimised implementation of various scientific approaches is indispensible. Hence, grain storages demand huge capital, maintenance and intellectual costs. Regardless of this concern, a well-managed grain storage system can facilitate in strengthening a stable food grain supply chain functioning year around.

Copious work has been done on storing different varieties of grain at different geographical and environmental conditions; however, there is a lack of research to understand the effects of climate change on stored grains. The objective of this work is to analyse available information of the factors that affect the quality of stored grain, and to speculate on the effects of climate change on grain storage, emphasising emerging challenges and to suggest feasible mitigation strategies in order to protect grain storages from the adverse effects of climate change. This paper also discusses the significance of mathematical modelling in this context and highlights the need for research in this field.

Climate Change and Grain Storage

The immediate notion of the term ‘climate change’ would be the rise in global temperature. Warm and humid conditions are not suitable for grain storage [39]. At such a scenario, stored grain is at a risk due to the favourable conditions developed for the growth and multiplication of different biotic factors. Changing seasonal patterns would promote favourable conditions for the growth and multiplication of insect pests in new geographical regions. For example, *Rhyzopertha dominica* (lesser grain borer) which is native to the tropics is feared to develop as a serious pest in the UK [16]. Studies indicate that storage conditions in the African continent are expected to improve with the changing climate [47]; and to some extent in Asia [55].This is possibly because of earlier summers, higher temperatures, faster crop growth cycles, earlier harvest, following storage of sufficiently low moisture grain and reduced need for subsequent drying operations. Immediate storage of harvested grain (in warm condition), however, would result in threats due to moisture condensation; an issue that needs to be dealt with caution. But in Europe, risks are projected due to extreme weather events, such as the European heat wave of 2003 that had antagonistic effects on the agricultural production of Europe. From a different perspective, higher levels of precipitation, floods and storms are also predicted with higher frequency during winter [9]. This would in turn affect drying potential, subsequent storage quality and allied expenses. The following sections explain the effect of climate change on stored grain ecosystem and its components. Further, if not directly, changing climate trends can cause significant effect on other factors that

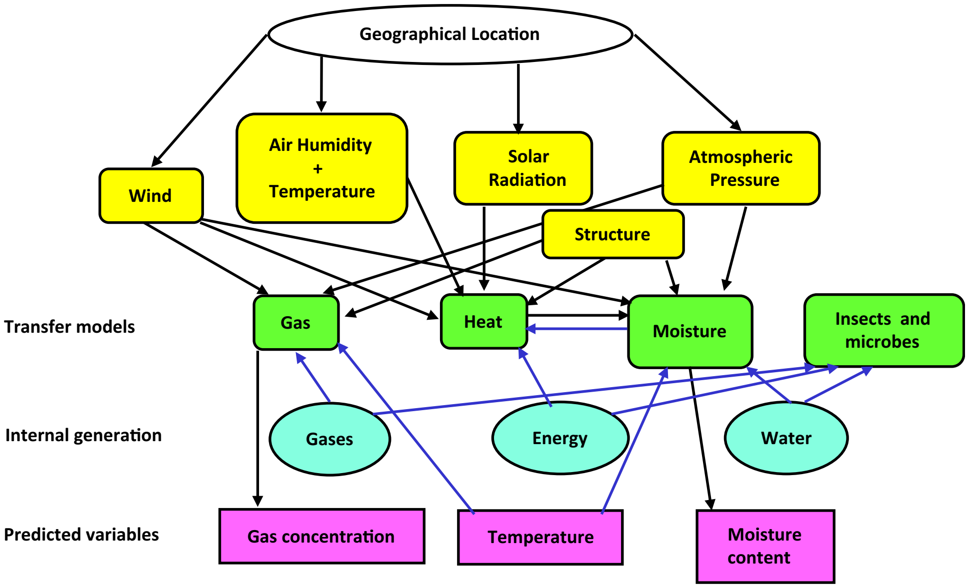

Fig. 1 Biotic and abiotic factors in stored grain ecosystems (*Source* [38])

would eventually affect stored grain quality as mentioned above.

Effects on Insects and Mites

Insects are the most influencing biotic factor in stored grain deterioration and offer an alarming threat, resulting in huge and often unrecorded economic losses. Outbreaks of infestations in several regions of the world have been closely related with global warming. Some prominent examples are the tree infesting beetles of western Canada [51], locusts of China [57] and the European corn borers [56]. A similar relation can be assumed in case of stored grain insects too, as records of the past have established an unwavering link between a hotter climate and a severe infestation [57]. The effects of climate change on insects can be direct or indirect. Direct effects relate to the favourable growth and developmental conditions of these pests. This can be expressed in terms of "changes in geographical distribution, increased overwintering, changes in population growth rates, increases in the number of generations, extension of the development season, changes in crop pest synchrony and changes in interspecific interactions" [56]. Indirect effects are concerned with the action on the endocrine systems, predators and parasites, microflora and other man-made barriers [68]. This would include the effects of mediation by host species, competitors or natural enemies [8].

In general, delayed winters and rising seasonal temperatures would permit shorter periods for pests to complete their developmental cycles, thereby resulting in a much rapid built up in their populations. With respect to the insect type, different stages of its life cycle will show different levels of tolerance to climate change. For instance, eggs of *T. confusum* are the most sensitive to increasing temperature [13] and those of *Sitotroga cerealella* to CO_2 [32]. However, it is the larvae stage in case of *O. surinamensis* [31] and the adult stage in case of *L. serricorne* and *S. paniceum* that are the least tolerant to increasing levels of CO_2 [30]. The effects of climate change vary from species to species and region to region. Nevertheless, from an ecological standpoint they may be categorised as: changes in abundance, distribution, phonology [81] and metabolic activity.

The survival temperatures for stored product insects range between 8 and 41 °C [68] with optimal temperatures between 25 and 35 °C for most insects (Table 1); the typical day-time temperature range in regions close to the equator. Major grain producing developing countries such as India, China and Thailand fall in this region and already suffer huge storage losses due to insect infestation worsened with improper grain storage practices. Rising temperatures will also force certain insects to migrate towards cooler regions towards the pole or to regions of greater elevation, to sustain their population. Insects that fail to adapt would face extinction or may develop as highly resistant species. As a computed measure that predicts the infestation severity of insects, the climate plasticity index (I_p) is expressed as a measure of the insect's adaptability, particularly with the changing temperature. It is calculated by considering the average reproductive potential of an insect at a particular temperature, followed by an integration analysis over relevant regional parameters. Sinha and Watters [68] approximated this function to find *Tribolium castaneum* and *T. confusum*, the major cosmopolitans top the list (Fig. 2).

Insects commonly grow close to the surface of the storage structure for want of oxygen. It is assumed that this characteristic feature would restrict their growth in cooler climatic zones [67], particularly because at temperatures below 10 °C, most insects become less active with low feeding capacities. Fatal effects due to starvation can also be expected. However, the behaviour does not remain the same for all grain storage insects. For example, psocids move towards warmer regions of the grain bulk—usually to the center—allowing their populations to continue to grow, even during colder seasons ($T < 20$ °C) [71]. Species such as *C. ferrugineus* have also been observed to move downwards in a grain mass and also towards warmer temperatures in grain [80], so as to adapt to varying environmental conditions. WitGrowth range and life-cycle information for selected storedh their increasing ability to adapt to different conditions, many insects are assumed cosmopolitan. Classic examples would be the dormancy period termed 'diapause' in species such as *S. cerealella* and *Plodia interpunctella* [36] and the inherent cold hardiness of *Trogoderma granarium* [23]. Such adaptation strategies are of great significance in temperate climates and hence demand more well-planned mitigation strategies.

Several other important considerations make prediction of insect population dynamics more complex and challenging. Competition to survival between different insect species within the same storage system [81] and the action of species that contribute to stronger biological control in stored bulks [76] are examples. The latter includes the growth and development of both parasitic wasps and entomopathogenic fungi in milder, wetter winters with increased atmospheric humidity.

Yet another important invertebrate pest is grain mites. Mites are known to develop well in temperate areas and particularly on damp grain. Nevertheless, their presence in warmer climates cannot be ignored [52]. Species such as *Tyrophagus putrescentiae* (Schrank) would show high tolerance to increased temperatures and can multiply rapidly above 30 °C [18]. These mould mites are commonly present in improperly stored high-lipid/protein content grains and are known to produce several allergens. Sinha's [65] conclusion that seasonal variations would have an effect on mites population, indicate that climate change would also have similar effects. On the whole, however,

Table 1 Growth range and life-cycle information for selected stored product insects and mites (Compiled from: [35], [69], [68])

	Temperature range (°C)	Optimum temperature (°C)	Rate of increase*	Life cycle period (days)
Insects				
Callosobruchus maculatus (F.)	18–35	30–32	NA	18–33
Corcyra cephalonica (Stainton)	17–35	28–32	10	40–50
Ephestia cautella (Walker)	15–32	28–32	50	27–83
Lasioderma serricorne (F.)	20–37	29–30	20	30–50
Oryzaephilus surinamensis (L.)	18–38	31–34	50	30–45
Plodia interpunctella (Hubner)	18–33	26–29	30	50–65
Rhizopertha dominica (F.)	18–39	33–34	20	50–65
Sitophilus oryzae (L.)	17–35	26–30	25	30–40
Sitotroga cerealella (Oliver)	16–35	26–30	50	35–50
Stegobium paniceum (L.)	15–35	25–27	7.5	55–65
Tribolium casteneum (Herbst)	20–40	32–35	70	26–48
Trogoderma granarium (Everts)	24–41	33–37	12.5	45–70
Mites				
Acarus siro (Oudemans)	3–31	24–25	2,500	NA
Cheyletus eruditis (Schrank)	8–34	23–27	NA	NA
Tyrophagus putresentiae (Schrank)	7–38	23–28	NA	NA

NA not available

* Per lunar month

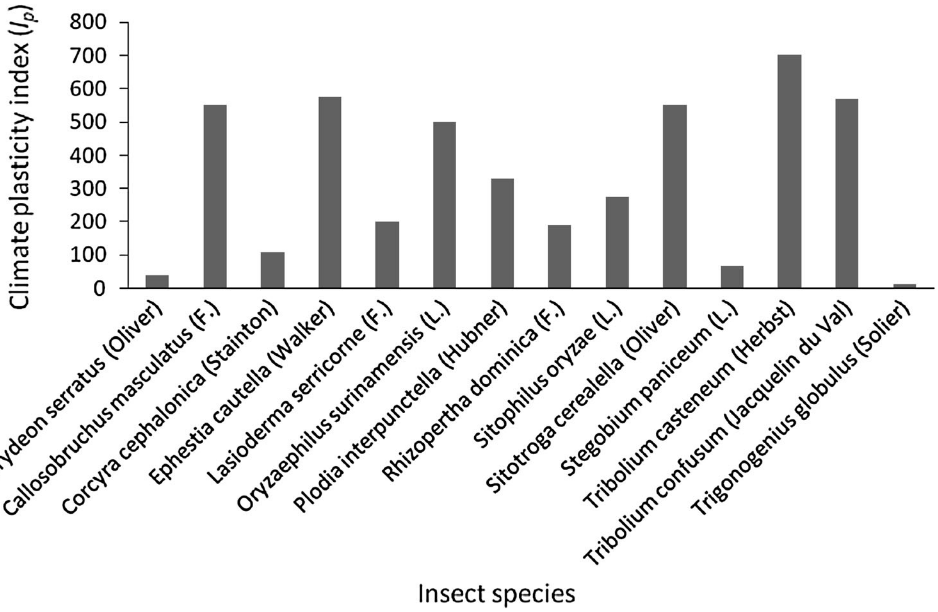

Fig. 2 Climate plasticity index (I_p) of selected stored grain insects (*Source* [68])

there is limited information on the effect of climate change on the growth of mites [15] and there is necessity to carry out well-structured experimental work to study the effects of changing climate trends on pests of stored products.

Effect on Microorganisms and their Metabolites

Among the other biotic factors that would show notable changes with the changing climate trends is the growth and development of microorganisms; fungi in particular. In normal conditions bacteria do not grow on grain, though spores are present always. However, the role of lactic acid bacteria under anaerobic conditions is significant. Fungi are commonly present on grain surfaces and within seed coats. In most climatic conditions, some of these fungi are known to produce secondary metabolites (mycotoxins). Aflatoxins are the most important mycotoxins and are commonly identified in agricultural commodities such as corn, peanuts, copra and nuts. They are extremely toxic, carcinogenic and immunosuppressive [17] and get introduced into food and feed systems by microorganism such as *Aspergillus flavus* that are considered thermo-tolerant.

Production of mycotoxins is influenced by two major factors: temperature and moisture content. Apart from aflatoxins, the production levels of other toxins such as fumonisin, secalonic acid D, ochratoxin A and deoxyinivalenol can also increase with increasing water activity (a_w) and due to temperature build-up within the storage unit. With changing climate trends, increased exposure to UV-B radiation would enhance the rates of certain mutation reactions associated with mycotoxin production because certain mycotoxigenic species tend to mutate as a response mechanism to climatic variations. Magan et al. [44] in their study concluded that variations in gas composition (particularly elevated levels of CO_2) and temperature with water availability could stimulate the development of certain mycotoxigenic species. Hence climate change would have significant effects on mycotoxins production in stored food grains. Table 2 summarises some of the predicted effects of climate change on mycotoxin production and related effects in various regions of the world. Fungal spoilage and mycotoxin contamination in stored grains are serious issues and their rates are highly dependent on temperature, gas composition and grain moisture contents. While the optimal temperature for the production of most mycotoxin types is between 25 and 30 °C (Table 3); the most threatening species, *A. flavus* can survive up to 48 °C and would pose an alarming concern with the rising global temperatures [3]. Also once produced, mycotoxins can withstand temperatures up to 180 °C, allowing it to continue in the food/feed systems in spite of the several processing operations involved [41].

Wheat stored at high moisture has high chances to harbour aflatoxin contamination [60] and so is the case for most food grains stored with $> 16\ \%$ moisture [9] corresponding to $a_w > 0.70$. Also, high-lipid cereals in warm climates are the perfect habitat for filamentous storage fungi such as *A. niger, A. tamarii*, *Penicillium oxalicum, P. citrinum* and *P. crateriforme* [63, 79]. In worst cases fungi infection can be expected in storages under poorly maintained on-farm or in-house levels [75]. In such storage practices, there is poor barrier to climatic variations, the key agro-ecosystem driving force for mould contamination and the production of mycotoxins. Such systems are very common in most developing and under developed countries. Posing serious concern to human and animal health, mycotoxins on the whole are a major barrier in the global trade of agricultural commodities. Mycotoxin levels even up to > 50 ppb in grain are not acceptable [60]. Acute effects of consumption of food grains contaminated with mycotoxins while in field or storage that resulted in fatalities of large population groups have been recorded in the past. Two prominent cases are that of 1974 in India and 1982 in Kenya [6].

Storage pest may be attracted or repelled by fungal growth and metabolites [66]. The combined effects of such biotic factors are in most cases the major reasons for quality loss in stored grain. This makes any prediction process tedious and inaccurate if such synergistic/competitive effects are overlooked. Validated mathematical models can facilitate to predict the effects of climate change on fungal growth and mycotoxin production. A few long-term [25, 27] and short-term models available explain the impact of climate change on plant diseases. Marín et al. [45] used mathematical models to predict the effect of the growth of aflatoxigenic fungi; however, such studies are related to specified commodity and conditions. With the

Table 2 Climate change, mycotoxin production and related effects (*Source* [55])

Region	Effects
Africa	Acute aflatoxicosis
	Drought stress and subsequently enhanced mycotoxin production
	Higher levels of contamination
Europe	Risk to development of mycotoxigenic species native to other areas
	Rain at harvest would increase energy requirements associated with grain drying
Australia and New Zealand	Higher levels of CO_2 and UV–B radiation may stimulate pathogen evolution and thereby suppress host resistance
Asia	Elevated levels of percent mycotoxin per unit weight of crop extreme
	High temperature could result in extinction of fungal species
Latin America	Emergence of highly resistant novel aflatoxigenic species (e.g. *A. minisclerotigenes* isolates thrive well even at 42 °C)
North America	Numerous storage problems due to floods and rising temperatures
	Risk to more ‘high temperature mycotoxins’

Table 3 Stored grain mycotoxins and optimal temperature for their production (*Source* [61])

Species	Mycotoxin	Optimal temperature for mycotoxin production (°C)
Alternaria alternate	Alternaria toxins	25
A. tenuissima	Tenuazonic acid	20
Aspergillus flavus	Aflatoxins	33
A. ochraceus	Ochratoxin A	25–30
Claviceps sp.	Ergot alkaloids	23–26
Fusarium verticillioides	Fumonisins	15–30
F. graminearum	Deoxynivalenol	30
F. culmorum	Deoxynivalenol	26
Penicillium verrucosum	Ochratoxin A	25

present climatic conditions Deoxynivalenol (DON) production is a common concern in stored wheat [29, 49]. If storage moisture is higher, DON concentration would increase multi-fold [10]. A mathematical model was developed to study the effects of climate change on the DON production [74]. Despite the fact that the model is meant for field variables such as flowering date, regional rainfall and duration between flowering and harvest; it also includes relevant variables such as relative humidity and temperature, revealing possibilities for future work.

Effect on Grain Quality

Climate has an influence on grain quality starting from its role in seed quality, crop growth, harvesting and handling. It also affects grain quality during every level of storage and transportation. Changes in grain quality during storage may be attributed to the following: (a) grain condition, (b) invasive forces, (c) grain treatment and (d) environmental conditions [72]. Environmental conditions pertain to the storage temperature, relative humidity, atmospheric conditions and the type of storage structure. Of these, rising temperatures and greenhouse gas levels are among the major concerns linked to climate change [48]. As a matter of fact, it is these factors that would also show a significant effect on stored grain quality. Apart from the direct effect of environmental conditions, grain heating also occurs due to two other reactions: biological heating (due to respiration of grain, microorganisms and pests) and chemical heating (due to oxidative reactions). Jian and Jayas [40] have described the sequential steps involved in the formation of hotspots and their effect on grain quality. The reaction rates of these phenomena are extremely reliant on climatic conditions. Further, progressive development of an existing hotspot is also dependent on the ambient temperature [77].

Respiration of stored grain at aerobic conditions is an exothermic reaction that involves the oxidative breakdown of glucose into CO_2, water and energy (heat). The reaction rate is primarily controlled by moisture, temperature, grain condition (including history) and aeration during storage. These factors have shown interdependency and play a considerable role in grain quality deterioration. With an increase in temperature, the respiration rate of grains increases. This results in an increase in a_w within the stored bulk. In the climate change context, particularly due to damp winters and subjected to improper aeration systems; the temperature of the stored bulk grain increases under damp conditions at a much faster pace developing favourable conditions for grain deterioration [7]. Grain spoilage reactions occur when the moisture content ≥ 0.70 a_w. This means threat to even existing grain storage systems. Further, heavy rains/unexpected weather events just before harvest time cause farmers to harvest and store immature kernels. These are known to have higher respiration rates and thereby increase the rate of subsequent microbial/insect activity. By and large, it turns out to be a vicious circle. Grain may be safely stored for several years if only the moisture content and temperature are kept low.

Grain storage under adverse conditions such as increased relative humidity, moisture content and temperature has direct links to quality losses. Table 4 summarises some of the probable effects of such conditions on grain quality. The results obtained from various grain storage studies show nutritional, bio-chemical, toxicological and other effect during storage. Changing climate trends (in particular, rising temperature and CO_2 levels) would lower the protein and micronutrient levels in food grains [14]. In the global market, the germination capacity of grain is regarded as a prime indicator of grain quality; but is drastically affected when the storage temperatures exceed safe limits. Another common concern with grain stored under such conditions is the reduction in cooking quality that would have subsequent effects on cooking energy requirements, palatability issues and reduction in protein quality.

Table 4 Quality changes in grains stored in adverse conditions

Grain	Storage condition	Quality changes	References
Barley	High moisture content	Fungal growth and mycotoxin formation Reduced vigour of seedlings, loss in beer quality (over foaming, poor flavour)	[1, 11]
Maize	High temperature	Increase in titratable acidity, decrease in total soluble sugars High risk to mycotoxin contamination	[59, 72]
Pinto beans	High temperature, high moisture content	Increase in free fatty acid value, colour change	[58]
Red lentils	High temperature, high moisture content	Appearance of visible mould, reduced germination	[70]
Rice	High temperature	Reduced sensory value, colour change	[53]
Soybean	High temperature, high relative humidity	Change in end-product quality: colour, texture and tofu yield	[34]
Wheat	High moisture content	Increased respiration rate and drop in germination	[42]

The formation of free fatty acids is common issue for grain stored quality. Oilseeds are more sensitive than grains to deteriorative lipolytic/oxidative chemical reactions. These are characterised by the formation of off-flavour/rancid components. The reaction rates are highly dependent on grain temperature and moisture content. Improperly stored oilseeds have poor market value and there have also been instances when huge quantities of grain have been recalled and termed not fit for human/animal consumption.

Other Related Effects

Rodents

Rodents result in losses over 10 % of stored food grains [2]; though often higher in terms of indirect losses due to contamination, damage to storage structure and spread of diseases. Also, the levels are multi-fold higher in most parts of Africa. A noted effect of rodent population is their ability to carry insects, mites and microorganisms between stores, turning a local population virtually into a regional or even network. Understanding the effect of changing climate trends on vertebrate pest (rodents in particular) multiplication and behaviour is of importance to grain storage management. For example, rainfall is an initiator for the outbreak of rodent pest [64]; an issue that is to be taken very seriously. Happenings in the past, such as the emergence of rodent populations in 1994 in India, 1993 in South America and 1992 in the United States, soon after extreme weather events allow to conclude that the effects of climate change on rodent populations is significant [5].

Agriculture Production and Economics

Countries with the fastest population growth; most of them in the equatorial region would be extremely vulnerable to the impacts of anthropogenically induced climate change. It is these areas that would be subjected to significant changes in seasonal patterns and weather events and allied aspects such as cropping systems, crop productivities, production strategies, freight and transportation systems, economic policies, export regulations, international grain markets and public distribution schemes are expected to undergo significant changes in the coming years.

Rising Production, Storage and Associated Costs

An appropriate approach to counter act changing climate patterns is to design and develop efficient storage structures that would be less affected by environmental changes. This, however, is subject to added expenses in terms of technology, fuel, energy, labour and space. Annually, the costs for grain storage show rising trends; particularly during warmer seasons [26]. Such seasons are characterised with heavy aeration requirements. Food supply systems of most countries are very delicate and show severe instability during times of urgent need. A classic example in the recent past is the devastating effect of the East African drought of 2011. Proper post-harvest grain storage practices can save huge quantities of stored grain annually. A kernel of grain saved is equivalent to a kernel of grain produced [38]. Strengthen food security can eventually minimise the pressure on food production [33].

Mathematical Modelling of Climate Change Consequences

The impact of climate change on agriculture can be studied using the Ricardian model or using the agronomic production function [21]. The former empirically estimates the direct impact of climate on net revenue. The latter; however, predicts the change in crop yield in response to climate using a crop simulation model. Several computer-based crop development models are in use to simulate the effects of different agricultural conditions on crop growth and yield. Some of them include: INFOCROP [4], STICS [12], SOYGRO [22] and WOFOST [20].There are also crop simulation models such as: empirical yield models and farm-based agro-economic simulation models that predict the economic impacts of climate change on agriculture [46].

In the present context, several complex interactions occur in stored grains. It is essential to understand the effects of all such parameters simultaneously. Stored grain is a dynamic system and hence makes mathematical modelling a challenging problem [39]. In other words, relationship between climatic variables and various biotic and abiotic grain storage attributes may not essentially be considered as additive co-variables for statistical models; rather involve more multipart interactions. Any study/guideline developed must take this into account. A few related works are mentioned here. The Ricker's classic equation is a simple model that has been used to predict the population density of *T. confusum* and *C. chinensis* under climate change scenarios [24]. The approach also gives a prospect to understand the relationship between climate change and invasive species [78]; particularly in connection with their habitats. The developed simulation model could predict future pest statuses in terms of population density at specific geographical locations. Magan et al. [44] developed an index of dominance for storage fungi(I_D) that is dependent on (a_w), temperature and grain substrate (and insect pests in some cases). It could explain mycotoxigenic fungi colonisation patterns, niche overlaps and dominance in grain storages. The relationship considers the role of other environmental factors and contaminant moulds. Daily and Ehrlich [19] explain a stochastic simulation model that could describe the impact of climate change on the world food scenario (in terms of production, consumption and storage of food grains).

Nevertheless, only few models have been developed to predict the quality of stored grains in terms of germination capacity, respiration and appearance of visible moulds, production of off-odours, pest infestation and related aspects [28]. Validated models developed from such studies could better simulate the effects of climate change on stored grain ecosystems. However, there is immense need to develop mathematical relationships that directly explain the effect of climate change on stored grains. Though it is a challenging task, simulation models that can explain the complexity of the earth's climate and the effects of global warming in the context of food grain storage have become quiet essential; particularly theoretical models of high predictive efficiency.

Conclusion and Directions for Future Work

Rising temperatures and greenhouse gas levels adversely affect agricultural productivity and grain quality. Perhaps, an overlooked facet of food security is the effect of climate change on grain storages. More often than not, grain storages are subject to intricate interactions among several biotic and abiotic factors that ultimately affect grain quality. Cautious long and short-term planning is indispensable. Deterioration of grain quality may be delayed or arrested by adopting proper management techniques. In this context, research work is needed in

(1) Checking the feasibility of organic agriculture as an adaptation strategy to climate change;
(2) Developing multi-geographically valid mathematical relationships that can effectively predict the effects of climate change on various aspects of grain storages;
(3) Explaining the underlying mechanisms of existing field/lab-scale results of various research works (subject to several variable constraints), so that they do not remain phenomenological but would be applicable;
(4) Studying the scope of use of tolerant/resistant crop varieties in agriculture to improve agricultural productivity;
(5) Understanding the feasibility of hermetic storage systems as sustainable alternatives to alleviate problems in grain storages subject to changing climatic patterns;
(6) Reviewing the possibility of biotechnological and genetic engineering interventions in developing food grain varieties that would show minimal effects to the action of various biotic and abiotic factors in stored-grain.

Global climate patterns have shown to change notably even from the previous decade. Their effects are complex and one may be misled if conclusions are drawn solely from the results obtained from research work considering a single independent variable (e.g. relative humidity alone). In most cases, well-studied complex interactions between several variables yield a more practically applicable result. Hence, an understanding of the effect of climate change on grain storage is multifaceted and requires multidisciplinary research. Therefore, several results of former studies need to be updated to stay relevant to the present scenario. Stored grain ecosystems are created and controlled by human beings. Hence, the ability rests upon man himself to develop and preserve stored grain to feed the growing world population.

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