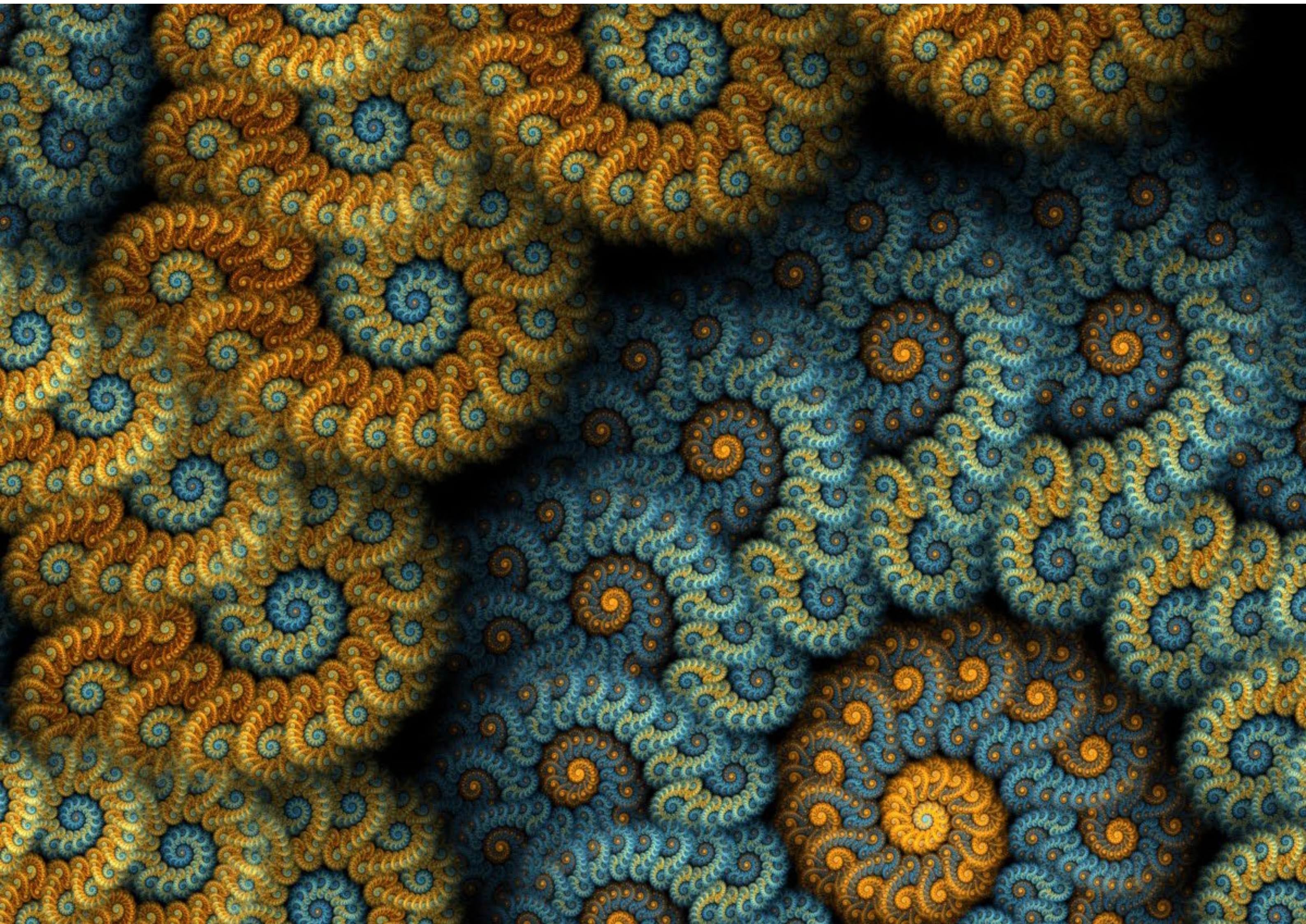
# Food Security: Impact of Climate Change and Technology



**Editors**
**Rachna Sehrawat, Hong-Wei Xiao, Sachin Vinayak Jangam, Arun Sadashiv Mujumdar**

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**2019**

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# PREFACE

With the global population to reach a staggering figure of 9.8 billion by 2050 requiring about 50 percent increase in production of food. There is no new landmass available to continue production and consumption of food at current rate. Indeed, the extra landmass needed to meet this production level is estimated to be an area twice that of India. Clearly, food security is by far the most critical BIG problem of this century. Problems of climate change and water shortage are critically important as well as they directly affect issues of food security.

Fortunately, both developed and developing countries now recognize the multifarious issues affecting food security. There is no multidimensional, multi- and trans-disciplinary problem that matches the complexity of food security issues. A holistic solution requires political, cultural, social, scientific as well as technological approaches on a truly global scale. Food insecurity can lead to geopolitical skirmishes leading to lack of peace around the world. This freely-downloadable e-book is being brought out to provide a simple practical guide to identify the scope of the problem and potential technological solutions to alleviate it. Clearly, a concise book like this cannot cover all the important issues but we hope it makes a serious first attempt to uncover the problem and identify some of the technological problems. We believe most readers will be able to come up with their own ideas and make a positive contribution to solving this big problem in decades to come. The sooner we begin the better.

Drying is a unit operation that has been critical to food security since time immemorial. Early humans recognized the need to get rid of water to be able to store animal and plant based edible foods over longer periods which is essential to their survival. Obviously, we can safely claim “drying” has been central to the survival of the human race itself. In this book we present a general overview of the role of drying in ensuring food security as it encompasses a whole range of dehydration problems from drying of seeds, grains, fruits and vegetables, meats, marine products, biomass and fertilizers. Drying is important to allow long term shelf-life, economic transport of perishable foods and even to minimize food waste or generate energy or by-products from food waste.

Climate change resulting in global warming has a massive adverse effect on the production of foods of all kind. The first chapter discusses this matter in considerable detail. It is clear that it is essential to follow practices that will minimize greenhouse gas emissions in order to secure food supplies. The chapter on diet explains why plant-based foods are much more sustainable and indeed healthier choices. Increased consumption of plant based foods will reduce strain on resources. Indeed, new sources of nutritious foods are needed. Much interest has appeared in including a wide variety of insects as a source of proteins. Furthermore, as all foods are perishable and subject to microbial degradation it is necessary to devise ways of mitigating such loss. Indeed, wastage of food at various stages of its production, processing, storage as well as consumption is a critical factor in influencing the potential of food insecurity. It is impossible to eliminate waste but it is possible to minimize it. These topics are covered in some depth in this book in a series of chapters. The importance of drying technology in the areas of preservation, storage and transportation of various goods has already been mentioned. Various dryer types and their applications relevant to food security are discussed in a separate chapter.

We hope that this concise e-book will be of wide interest to readers in a wide range of disciplines. We feel that it is high time everyone needs to do her/his part in ensuring food security in the next several decades. The topic of food security indeed needs an encyclopedia to do justice to all the topics and subtopics that are crucially important to food security. We believe this book is a brief introduction to the important aspects of the problem and some ideas about how the problem may be resolved in the coming decades.
We welcome feedback from our readers.

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# Chapter 1

# Diet change, food wastage and food security

***Li-Zhen Deng, Arun S. Mujumdar, Hong-Wei Xiao***

## Contents

## 1.1 INTRODUCTION

Over the last few decades, worldwide increase in incomes has driven a diet transition, which is characterized by low intake of fruits, vegetables, and whole grains, in place of high consumption of refined carbohydrates, fat and animal products (Popkin et al., 2012; Tilman et al., 2014; Godfray et al., 2018). This diet shift has presented challenges on human health and environmental sustainability. The diet change increases the incidence of energy imbalance, overweight, obesity, and cardiovascular disease (Popkin et al., 2012). The increase in meat consumption has severe impact on the global environment (Eisler et al., 2014; Tilman & Clark, 2014). As compared to the plant-based foods, livestock production releases much higher amounts greenhouse gases (GHGs) (Godfray et al., 2010, 2018), as the ruminant has the largest contribution of GHGs, about 49-64 kg methane produces per cow at per year (Nijdam et al., 2012). Meanwhile, livestock production is a primary competitor for water and land (Godfray et al., 2018), it uses a large plenty of natural resources, such as one-third of global cropland (Herrero et al., 2013; Eshel et al., 2014) and freshwater (Herrero et al., 2013; Godfray et al., 2018). Moreover, forests, grasslands, and natural habitats are converted to agriculture to meet global food demand, which will reach up to $10^9$ hectares by 2050 in case of the diet pattern and global population increase continue (Tilman et al., 2001). The land conversion destroys the global habitat (Tilman et al., 2001) and decreases the biodiversity (Godfray et al., 2018). Springmann et al. (2018) estimated that the 75% reduction of food wastage would reduce environmental pressures by 9%-24%. Therefore, diet change takes an important role in the global environmental change, especially when considering the increases in meat consumption (Tilman et al., 2001).

Food wastage is a serious problem and occurs on the entire food supply chain (FAO, 2013), as approximately 30%-40% of global foods are wasted annually (Godfray et al., 2010; Fischer, 2018). In middle- and high-income countries, food wastage is driven by the low price of food relative to disposable income, and consumers' high expectations of food standards (Parfitt et al., 2010). Consumers and retailers contribute to a plenty of wastage, this accounts for 21% and 10% of the whole food wastage, respectively (Newsome et al., 2014). Beside, a massive amount of food wastage takes place during harvest, postharvest and storage steps, especially in the developing countries, owing to poor infrastructure of food production and post-harvest processing, lack of skills in storage, inadequate management capacity of supply chain (Kummu et al., 2012; Parfitt et al., 2010). Food wastage damages food security, global environment and economic development (Newsome et al., 2014; FAO, 2011 & 2013), expands valuable natural resources (Betz et al., 2015; Kummu et al., 2012), it occupies about a quarter of land, water and fertilizer used for crop production (Shafiee-Jood & Cai, 2016). Reduction of food wastage will benefit for food security and environment, and feed more people without extra natural resource occupation and global environment change (Nicholls, 2010).

There has been a marked growth in food production during the past half-century, which dramatically decreased the global hungry proportion. Currently, however, appropriately 925 million people endure hunger and an additional 1 billion lack sufficient intake of nutrient (Newsome et al., 2014). What's more, the world population will increase by 36% from 2009 to 2050 (Tilman & Clark, 2014), and come up to 8.5-10 billion in 2050 (Springmann et al., 2018). Therefore, feeding the growing global population is still a challenge (Tilman et al., 2001; Naylor, 2011), it will demand 70% more food in 2050 to guaranty the food security (Jalava et al., 2016). However, agriculture production highly depends on climate condition (Porter et al., 2014), and global warming and the frequency of extreme events are threatening agricultural production (Schmidhuber & Tubiello, 2007; Hughes & Ebert, 2011). It is estimated that the global crop yields will decrease by 3%-10% for each degree rise in temperature of earth (Challinor et al., 2014). Livestock production and productivity also decreased as a result of climate change, owns to the availability of feed sources shortage reduced and the development rate of pathogens and parasites increased (Baumgard et al., 2012). Global food system is a major driver of environmental change and natural resources consumption (Springmann et al., 2018), if trends of population and income levels continue rising, the environmental effects of the food system would increase by 50%-90% in the absence of technological changes and dedicated mitigation measures between 2010 and 2050 (Springmann et al., 2018).

Therefore, we are facing a great food security challenge to meet global growing food requirements and reduce agriculture's environmental footprint. Here, in this chapter, on global diet change, food wastage and food security; we evaluate the effect of diet change and food wastage on global environment, and the impact of climate change on food security; then identify and discuss the solutions to the trilemma of diet change, food wastage and food security. Interested readers are encouraged to refer to the extensive literature cited for details.

## 1.2 DIET CHANGE

### 1.2.1 Global diet transition

As incomes around the world have risen, there are important global diet changes from the traditional patterns to that with high content of meats, alcohols, refined sugars, fats and oils, with reductions in consumption of vegetables, fruit and grains (Tilman & Clark, 2014). Over the past semi-century, the consumption of meat and dairy products increased rapidly, the global numbers of cattle, sheep, and goats increased 1.5 times, meanwhile, numbers of pigs and chickens have increased 2.5 and 4.5 times, respectively (Tilman & Clark, 2014). What's more, Tilman and Clark (2014) estimated that, from 2009 to 2050, total calories and protein will increase by15% and 11%, respective; the intake of pork and poultry, ruminant meat, dairy and egg, and fish and seafood will increase 23%, 31%, 58% and 82%, respectively; while, the consumption of fruits and vegetables, and plant protein will decrease by 18% and 2.7%, respectively. This dramatic rise in animal based diet has serious effects on food security and probably the health of the general population as well.

### 1.2.2 Diet change and human health

The diet change, particular high intake of meat, has increased the incidence of energy imbalance, diabetes, obesity, and the various nutrition-related cardiometabolic diseases (Popkin et al., 2012; Wang et al., 2016; Vergnaud et al., 2010; Godfray et al., 2018). For instance, in American, more than two-thirds of adults and nearly one-third of children are overweight or obese, and about a half of adults have poor diet related chronic diseases (Godfray et al., 2018). Increased risk of colorectal cancer and total mortality rates have strong relationship with high intakes of processed meat (Godfray et al., 2018). Child obesity around the world is a new problem that will worsen unless corrective actions are taken.

### 1.2.3. Diet change and global environment

Global diet change intensifies the impact of agriculture on the global environment (Eisler et al., 2014; Tilman & Clark, 2014). Agriculture production generates greenhouse gases (GHGs) ($CH_4$, $N_2O$ and $CO_2$), environmental pollution, water shortages, soil degradation, biodiversity loss and ecosystem disruption (Godfray et al., 2010), and the livestock production presents major adverse effects on the environment (Godfray et al., 2018; de Vries & de Boer, 2009, 2010; Nijdam et al., 2012).

#### *1.2.3.1 Greenhouse gas*

Agriculture production contributes to a large proportion of greenhouse gases (GHGs) emission. Springmann et al. (2018) estimated that the food system released around 5.2 billion tons of $CO_2$ equivalent (eq.) in 2010. Animal-based foods have higher GHGs emissions than plant-based foods (de Vries & de Boer, 2010; Godfray et al., 2018). For instance, beef and lamb meats have emissions per gram of protein that are about 250 folds than those of legumes (Tilman & Clark, 2014). Ruminant has the largest contribution of GHGs, the rumen fermentation produces a mass of methane (49-64 kg per cow, per year) (Nijdam et al., 2012). Based on the data reported by Herrero et al. (2013), total non-$CO_2$ GHG emissions from the livestock production were 2.45 Gt $CO_2$ eq. in 2000, enteric fermentation from ruminants generated 1.6 Gt $CO_2$ eq. of methane emissions. By contrast, poultry products have relative lower GHGs emissions, which around 3 kg $CO_2$ eq. per kg of chicken meat (Nijdam et al., 2012). What's more, if global diet changes continuing, the global average per capita diet GHG emissions from crop and livestock production would increase 32% from 2009 to 2050 (Tilman & Clark, 2014).

#### *1.2.3.2 Soil degradation and farmland shrinking*

Diet change is an important driver of cropland requirements, and it may surpass population growth in the near future (Kastner et al., 2011). Global cropland increased by approximately 270 Mha from 1963 to 2005, as a result of population increase and diet change (Kastner et al., 2011), and 12.6 million $km^2$ of cropland used in food system in 2010 (Springmann et al., 2018). The livestock sector is the largest use of land globally, it occupied one-third of global cropland (Herrero et al., 2013; Eshel et al., 2014). What's more, a $10^9$ hectares of natural ecosystems would be converted to agriculture in 2050, if the global population increase and diet change continues (Tilman et al., 2001). A case study of US, the animal-based food occupies 0.6 million $km^2$ for crops and processed roughage, equivalent to 40% of all US cropland, meanwhile, the total requirements (including pasture land) come to 3.7 million $km^2$, relative to 40% of the total land area of the US (Eshel et al., 2014). Food production caused around 32% of global terrestrial acidification and 78% of eutrophication (Poore & Nemecek, 2018), which associated to slather fertilizer, appropriately 104 and 18 teragrams of nitrogen and phosphorus in the form of fertilizers was used to food production in 2010, respectively (Springmann et al., 2018). However, the pressures on land resources to meet the food requirements would probably be remaining high in near future due to the diet change (Kastner et al., 2011).

#### *1.2.3.3 Water shortages and eutrophication*

Agriculture production uses the largest amount of freshwater among human activity; it accounted for used 1810 $km^3$ of freshwater resources in 2010 (Springmann et al., 2018). Around two-thirds of freshwater withdrawals has been used for irrigation (Poore & Nemecek, 2018), and one-third of the freshwater required for livestock (Herrero et al., 2013; Godfray et al., 2018). Quantitatively, meat production used 45 billion $m^3$ of water, equivalently 27% of the total national irrigation use, or 150 $m^3$ per person per year in US (Eshel et al., 2014). Hence, meat production is an important competitor with other uses of water, especially in water-stressed areas (Godfray et al., 2018).

Moreover, food production is an important factor contributes to water eutrophication. Excessive fertilizers are used for crops to increase the production, but only 40%–50% of the nitrogen has been utilized by plant, the surplus would go to waste and pollute lakes and streams (Gewin et al, 2010). Besides, a vast N and P from animal wastes enter surface and groundwater, consequently, cause the eutrophication, including lakes, streams and coastal seas, and the groundwater pollution (Tilman et al., 2001). In addition, the additional N would probably to increase the greenhouse gas $N_2O$, and acidification of soils (Tilman et al., 2001).

#### *1.2.3.4 Biodiversity loss*

Agriculture is a major threat for biodiversity worldwide. Land conversion to agriculture to meet global food demand comes from forests, grasslands, and natural habitats, this destroys the global habitat, causes the loss of native ecosystems (Tilman et al., 2001). Furthermore, combined with overgrazing, biodiversity loss would be more serious (Godfray et al., 2018). Therefore, agriculture production has caused has serious impact on the global environment, and meat-based food production plays a greater role in global environmental change than plant-based food.

The conversion efficiency of plant into animal matter is very low (about 10%), particularly for ruminant (Godfray et al., 2010). For example, beef production requires 28, 11, 5, and 6 times more land, irrigation water, GHG, and Nr, respectively, as compared with the mean of other livestock categories (Eshel et al., 2014). Herein, diet change promotes the global environmental change. And if the impact of agriculture on environment continuing, the unprecedented ecosystem simplification, loss of ecosystem services, and species extinctions would take place (Tilman et al., 2001). Potential problems of water resource shortage will be critical in future in areas already suffering from low supply.

### 1.2.4. Healthy and sustainable diet is required

Diet change has caused a severe health and environment problems, while, almost a billion people still suffer from insufficient diets and insecure food supplies (Godfray et al., 2010; Tilman & Clark, 2014; Godfray et al., 2018), and about one-third of global cereal production is fed to animals (Godfray et al., 2010). Therefore, in terms of the environmental impact, health and food security perspective, strategies are needed to converse the global diet to a healthier and sustainable pattern, with a higher proportion plant-based foods and lower animal-based foods. Meanwhile, food system sustainability has been recommended to be an integral part of diet guidance in the 2015 Dietary Guidelines for Americans by the U.S. Dietary Guidelines Advisory Committee (DGAC, 2015).

Reducing meat consumption, transition from red meats and high impact seafood towards vegetal foods, white meats, and sustainable seafood products, will bring potential health benefits, such lower the incidence of diet-related chronic non-communicable diseases; and mitigate environment stress, such as decrease the GHGs emissions, land and water occupation and environment pollution (Tilman & Clark, 2014; Nijdam et al., 2012). Besides, reducing the consumption of meat will provide an opportunity to feed more people (Godfray et al., 2010). While, the diet patterns are influenced by complex factors, such as culture, nutritional knowledge, food price, taste and etc., and which should be taken into account (Tilman & Clark, 2014). Combination of environmental labels, taxes or subsidies aim to reflect environmental costs in product prices can be conducted.

## 1.3 FOOD WASTAGE

Food wastage takes place throughout the food supply chain, including harvesting, packaging, storage, transport, processing, marketing, and post-consumer (FAO, 2013). It offers serious impact on food safety and quality, food security, the environment (including land, water, biodiversity, and global climate), and economic development (Newsome et al., 2014; FAO, 2011 & 2013).

Food wastage has captured high global attention; there has been growing interest in establishing food wastage prevention and recovery programs to transition to more sustainable practices (Thyberg, 2015). And the United Nations Environment Program, FAO, and multiple partners issued in 2013 the “Think, Eat, Save, Reduce your Foodprint” campaign to decrease food wastage (Newsome et al., 2014).

### 1.3.1 Global food wastage

Food wastage has been formally defined in different legal jurisdictions. According to the FAO (2013), the food wastage includes any food lost by deterioration or waste, viz., both food loss and food waste. Food loss refers to a decrease in mass or nutrition of food, mainly caused by inefficiencies in the food supply chains; food waste refers to food appropriate for consumption being discarded (FAO, 2013). In fact, if there were no wasted food there would be no issue of food security for decades. We believe the reasons leading to serious wastage are multifarious and include geographical, climatic as well as social, cultural and technological. This discussion is beyond the scope of this article, however.

Wastage has generated serious economic, environmental, and social consequences. Approximately 30%-40% of food on a global scale is lose to waste (Godfray et al., 2010; Fischer, 2018). FAO (2013) estimated that about 1.3 billion metric tons of edible food was wasted on an annual basis globally. This wastage requires about one-quarter of land, water, and fertilizer used for crop production (Shafiee-Jood & Cai, 2016). In American, a 422g of food waste per person daily, accounts for 30% and 25% of daily calories and consumed food, respectively, and appropriately 30 million acres of cropland used to produce these foods annually, equals to 7% of annual cropland acreage (Conrad et al., 2018), food wastage by the retailers and consumers was equal to a value of $ 165.6 billion annually (Buzby & Hyman, 2012). When comes to China, the average person wasted was 16 kg of food at home annually, equivalent to 40 kg $CO_2$eq., 18 $m^3$, and 173 $gm^2$ for the carbon, water and ecological footprints, respectively (Song et al., 2015). The global annual lost and wasted food could feed nearly 2 billion people a 2100 kcal/day diet (Kummu et al., 2012).

### 1.3.2 Food wastage and global environment

Food wastage exerts a tremendous influence on the global environment and expands valuable natural resources (Betz et al., 2015; Kummu et al., 2012). Annually, the production of global lost and wasted crops accounts for 24%, 23% and 23% of total global freshwater, cropland area, and fertilizer used in food crop production, respectively (Kummu et al., 2012), more than 30 million acres of cropland, nearly 4.2 trillion gallons and 5.6 billion pounds of irrigation water and fertilizer were used to produce wasted foods, respectively (Conrad et al., 2018). Globally, the blue water footprint for the agricultural production of total food wastage was about 250 $km^3$ in 2007 (Mekonnen & Hoekstra 2011), it represents almost 3-folds of Lake Geneva in volume (FAO, 2013). According to the statistics from FAO (2013), the average carbon footprint of food wastage is about 500 kg $CO_2$ eq. per capita and per year. Besides, Food wastage aggravates the mono-cropping and agriculture expansion into wild areas, causes the simplification and degradation of habitats, and intensifies the biodiversity loss. Besides, meat wastage has overall high environmental impacts, since most of agricultural land is cleared for cattle pastures, results in increasing habitat fragmentation and degradation (FAO, 2013).

### 1.3.3 Factors associated with food wastage

Food wastage has been driven by numerous factors, such as weather, crop production choices and patterns, internal infrastructure, marketing chains, retail and food service operations, consumer purchasing and consumption behaviors, etc. (FAO 2011, 2013; Newsome et al., 2014; Verghese et al., 2013). These factors also vary around the world, depending on specific conditions and local situations, for instance, food is to a great extent wasted during consumption in medium- and high-income countries; by contrast, food is mainly lost during the early and middle stages of the food supply chain in low-income countries (Parfitt et al., 2010).

#### *1.3.3.1 Consumers and retailers*

Food wastage is greatly related to the behavior of retailers and consumers, which accounts for 10% (43 billion pounds) and 21% (90 billion pounds) of the whole food wastage, respectively (Newsome et al., 2014). In middle and high-income countries, food wastage is driven by the low price of food relative to disposable income and consumers' high expectations on food quality (Parfitt et al., 2010), which motivates the consumer- and retailers-level wastage (Godfray et al., 2010). Kummu et al. (2012) reported that about half of the food supply loss occur in distribution and consumption. As in case of American, 31%-40% of wastes take place in post-harvest food supply, and a substantial portion occur at the consumer level (Neff et al., 2015). Moreover, current commercial pattern encourages the food wastage, the food service industry and retailers usually use "super-sized" or "buy one get one free" as a competitive strategy, consequently, large amounts of food waste would be caused by consumer. Besides, consumers would discard unspoiled food due to misunderstand of various date labels on food packages (e.g. "sell by", "use by", and "best before"), which leads to significant unnecessary food wastage (Newsome et al., 2014; Wilson et al., 2017). It is urgent to take action to unify the date labeling to eliminate consumers' confusion (Newsome et al., 2014).

#### *1.3.3.2 Infrastructure, technology and knowledge*

A large amount of food wastage occurs during agricultural postharvest steps, especially in the developing countries, due to poor infrastructure and logistics in food production and post-harvest processing, lack of technology and skills in storage, inadequate knowledge and management capacity of supply chain, as well as inefficiently access to markets (Kummu et al., 2012; Parfitt et al., 2010). For example, in India, it is estimated that 35%-40% of fresh farm products are lost mainly attribute to the lack of cold storage (Nellemann, 2009). Therefore, increasing the investment in food storage, processing and transportation will be one of the practical solutions to reduce food wastage.

Besides, improper handling of unwanted food also aggravates additional wastage, for instance, unwanted food in some developed countries goes to a landfill instead of being used as animal feed or compost (Godfray et al., 2010). And there is appropriately more than one-third of the world's cereal grain consumed by livestock, and around 70% of the grains used by developed countries are fed to animals (Awika, 2011). However, the conversion efficiency of plant into animal matter is very low, hence, animals should be fed less human food. In addition, the food wastage has also been related to natural disasters, weather and climatic conditions, negative economic trends.

### 1.3.4 Solutions to reduce food wastage

Food wastage is a widespread phenomenon globally, it gravely threats the sustainability due to occupy a mass of natural resources (Conrad et al., 2018). It is urgent to take actions to reduce food wastage to feed the increasing world population, ease environment pressure and achieve the sustainable production (Thyberg et al., 2015; Springmann et al., 2018). In order to achieve this goal requires joint efforts of policymakers, food producers and suppliers, and food consumers (Shafiee-Jood & Cai, 2016). It is a difficult but necessary requirement to achieve food security.

#### *1.3.4.1 Decrease of wastage by consumers*

The greatest potential for the food wastage reduction in developed countries is offered by consumers and retailers. More efforts are required to reduce the food wastage during consumption, such as increasing the awareness of the serious impact of food wastage on the environment (Parfitt et al., 2010); provide appropriate food purchases guides to store food under optimal conditions (Newsome et al., 2014); change the consumer behavior via education and advocacy to avoid over-purchasing; and improve consumer's knowledge about the relationship between food safety and date labels, avoid to discard edible food (Hebrok & Boks, 2017; Thyberg & Tonjes, 2016). Besides, encourage consumer take restaurant leftovers home also helps to reduce wastage (Shafiee-Jood & Cai, 2016).

It is necessary to regulate or harmonize the date labeling language on food package (Wilson et al., 2017), which requires efforts by the food industry to carry out an accordant or single best practices date-marking system (Newsome et al., 2014). At the same time, a reasonable product size should be designed, since larger package sizes enhances the food wastage (Wilson et al., 2017), and a novel package could be developed to prolong the shelf-life (Newsome et al., 2014). In addition, legislations are probably needed to limit waste from the food service and retail sectors (Godfray et al., 2010).

#### *1.3.4.2 Increase of investment in supply chain*

Proper storage, processing and transportation play an important role in food wastage reduction. Increasing the investment in food storage, processing and transportation infrastructure helps to reduce the rate of spoilage and decreases losses due to unfavorable weather conditions (Shafiee-Jood & Cai, 2016; Godfray et al., 2010). About half of the losses could be reduced through a more efficient supply chain (Kummu et al., 2012).

#### *1.3.4.3 Improving wastage utilization*

A mass of unwanted or wasted food would be transferred to landfill instead of being recycle-used in some developed world (Godfray et al., 2010). Meanwhile, it is impossible to avoid all kinds of food wastage. Therefore, legislation and innovative techniques should be put forward and developed to boost wasted food recycling and improve resource utilization. Wasted food can be recycled as livestock's feed, compost, biopolymers, biofuels, or extraction of high-value components (Newsome et al., 2014; Girotto et al., 2015). For instance, South Korea has reduced food waste in terms of household and restaurant by 30%-40% through food waste recycling since 2005 (Zu Ermgassen et al., 2016).

#### *1.3.4.4 Others*

The redistribution of food to feed poor people by donation would be a feasible practice to reduce food wastage, which need supports by governments and public to facilitate the recovery and redistribution (Girotto et al., 2015). Reduce the human food to feed the animal, instead by increasing the silage and high-fiber crop residues that are unsuitable for human consumption (Eisler et al., 2014). Meanwhile, innovative technologies should be developed to provide accurate weather forecast information for farmers to arrange harvest time (Shafiee-Jood & Cai, 2016).

Generally, food wastage reduction requires global public participation, including food consumers, food suppliers, food industries, agriculturists, educators, and policymakers (Tilman & Clark, 2014; Shafiee-Jood & Cai, 2016). Food wastage reduction helps to feed more people without extra natural resource occupation and global environment change (Nicholls, 2010).

## 1.4 FOOD SECURITY

Food security is a serious global issue and has been highlighted in recent years (Naylor, 2011; Kummu et al., 2012). It has been witnessed that the global hungry population suffered a rapid increase from 800 million to over 1 billion affect by the 2007/08 food price crisis (Beddington et al., 2012), and regarded as an important factor which triggered the Arab Spring uprisings in North Africa and the Middle East in 2011 (Ball et al., 2015). Even if the rapid increase of food production and the population being starve have significantly reduced. However, food security is still a great challenge, due to the increasing population, limited farmland, rapid diet transitions, large food wastage, global climate change, etc. (Beddington et al., 2012).

### 1.4.1 Population increase

At present, an estimated 925 million people endure hunger and an additional 1 billion lack sufficient intake of high-quality protein, vitamins, and minerals (Newsome et al., 2014). Even in US, there are over 49 million people undergo food insecurity (DGAC, 2015). While, the world population is estimated to increase by 36% from 2009 to 2050 (Tilman & Clark, 2014), and the population will hit to 8.5-10 billion in 2050 (Springmann et al., 2018). The growing population would require 70% more food in 2050 (Jalava et al., 2016). However, the land available per capita has constricted from 13.5 ha in 1950 to 3.2 ha 2005, and it would further decrease to 1.5 ha in 2050 responds to the increasing population (Montgomery et al., 2007). And there is small space to increase yields by using more water, fertilizer and pesticide (Jalava et al., 2016). Hence feeding the growing global population remains a difficulty (Tilman et al., 2001; Naylor, 2011). Moreover, urbanization population rising also burden the food supplies, it increases energy demand for storing and transporting food and reduce land availability, thus aggravate the food security issue.

### 1.4.2 Climate change

Agriculture production damages the global climate, inversely, climate change also profoundly and lasting influences agriculture (Nelson et al., 2010; Vermeulen et al., 2012). Crop yields highly rely on climate condition, it will decrease as a consequence upon climate change (Porter et al., 2014; Schmidhuber & Tubiello, 2007; Hughes & Ebert, 2011). Climate change is being experienced as increases in temperature and the incidence and magnitude of extreme events.

#### *1.4.2.1 Global warming*

Crop yields decreased by 3%-10% for each degree rise in temperature (Challinor et al., 2014). On the one hand, global warming increase the metabolism, reproduction, and movement of insect pests, as well as the ability of pest to survive in winter (Schmidhuber & Tubiello, 2007; Gewin et al., 2010). Appropriate10%–16% of global production reduction relates to the increasing pests and diseases damage (Campbell et al., 2016). Moreover, crop flowering and maturity will ahead of time due to temperature increasing, hence shorten the time for carbon fixation and biomass accumulation (DaMatta et al., 2010). Besides, warming is likely to rise heat stress on crops, and affect the photosynthesis, then cut down the yields (DaMatta et al., 2010).

#### *1.4.2.2 Climate extremes*

The frequency of climate extremes is continually increasing in recent years, including droughts, heatwaves, heavy precipitation, heavy storms and extreme frost (Morton, 2007; Vermeulen et al., 2012), it strongly affects both crop yields and losses (Shafiee-Jood & Cai, 2016). Unstable climate threatens the yields of crops and disrupts food production in many regions in the world (Hughes & Ebert, 2011). Heavy precipitations limit the time for harvesting, increase the moisture content in the product which will be more perishable, meanwhile, crops can’t be efficiently dried to safety level (Stathers et al., 2013; Shafiee-Jood & Cai, 2016). Lesk et al. (2016) estimated that the national cereal production significantly reduced by 9%–10% owned to droughts and extreme heat.

Climate change also impairs livestock production and productivity (Baumgard et al., 2012). The availability of natural source including pasture, crop and water will decrease as consequence of climate change; the development rate of some pathogens and parasites will speed up and heat stress will appear owns to temperature rising; moreover, some indirect effects induced by climate change, such as immune systems alter and genetic resources loss (Tiruneh & Tegene, 2018). Therefore, climate change is a vital threat to food security.

### 1.4.3 Food security and potential solutions

The problem of food security is a great long-term challenge we are facing, diet change and food wastage are intimately related to food security. Both diet change and food wastage have markedly effect to global environment, while the climate change together with global population rising intensify the food security issue. Addressing food security challenge demands diet pattern shift, food wastage reduction and production increased.

#### *1.4.3.1 Change of current diet pattern*

Diet changes towards healthier and a sustainable pattern, which implies higher proportion of plant-based foods, instead of environmentally-intensive animal-based product, can relieve the environmental impacts of the agriculture production (Tilman et al., 2014; Merrigan et al., 2015; Springmann et al., 2016, 2018). It will benefit for reducing the emission of GHGs and the use of water, cropland, and fertilizers (Ruini et al. 2015; Jalava et al., 2016), thus ease the global warming, eutrophication, and solid degradation. Healthy diet patterns will improve food security for both the current population and future generations (DGAC, 2015).

#### *1.4.3.2 Reduce food wastage*

Reduce food wastage is deemed to be an important action required to improve food security and environmental sustainability in near future (Kummu et al., 2012; Shafiee-Jood & Cai, 2016). It becomes an increasingly important strategy to help feed the growing population (Thyberg et al., 2015). Food wastage reduction would increase the food availability and the resource utilization efficiency of in food production (Fischer et al., 2018), halving food loss would reduce 12% of both blue and green water (Jalava et al., 2016), and feed one billion extra people (Kummu et al., 2012). Furthermore, a 75% reduction of food wastage has been estimated to achieve 9%-24% reduction of environmental pressures (Springmann et al., 2018).

#### *1.4.3.3 Increase of efficiencies in agricultural production and use of natural resources*

Increasing the agricultural yields will reduce the additional cropland demands owing to population growth and diet change (Kastner et al., 2011). Strategies via overusing fertilizers, water and pesticides during the “Green Revolution” dramatically increased the food yields (Sachs et al., 2010) are now failing to meet growing food needs (Gewin et al., 2010), due to its serious environmental problems (Gewin, 2010). Modern innovative techniques and management approaches should be applied to increase food yields with higher use efficiency of natural resources and lower environmental impacts (Springmann et al., 2018). The following is a list of actions needed.

- Using of genetic engineering to develop new varieties of crops and animals with higher production and immunity to diseases, and lower GHGs emissions (Godfray et al., 2010; Uphoff et al., 2010);
- Cultivation of new crop varieties withstand water- and nutrient-deficient soils to combat climate change (Gilbert, 2010);
- Change the irrigation and fertilization process, increasing nitrogen, phosphorus and water use efficiency;
- Increase the efficiency of feed conversion and production of meat and milk by means of better rearing management and improve feed quality (Godfray et al., 2010; Herrero et al., 2013);
- Adoption of feed additives or supplements to reduce enteric fermentation in livestock, and then lessen the emissions of by-product greenhouse gas and ammonia (Eisler et al., 2014).

On the whole, no single measure is sufficient to address the food security problem, strategies should be combined, and feeding the world requires the and the joint efforts by cross-disciplinary study, political engagement and public participation. A cultural and social change is needed for the general population to recognize how critical it is to reduce wastage to the minimum.

## 1.5 CONCLUSION

Food yields and income increasing facilitate diet changing and food wastage. Both of diet change and food wastage burden the global environment and aggravate climate change. The diet change, particularly for high consumption of meat, give rise to large greenhouse gases emission, environmental pollution, water shortage, soil degradation, biodiversity loss, and ecosystem disruption. Meanwhile, food wastage has caused natural resource waste, economic loss and environmental destruction. As a consequence, the climate change, solid degradation, and natural resources shortage would decrease the food production.

However, we are facing a huge challenge of food security. Since about 925 million people are enduring hunger and an additional 1 billion in malnutrition, moreover, the world population will be continually increase up to 8.5-10 billion in 2050. Therefore, feeding the growing global population under climate change is a tremendous issue. It is imperative to address the trilemma of food security–diet change–food wastage. In summary, taking actions to shifting current diet pattern towards healthier and sustainable one, which with higher consumption of plant-based food and lower intake animal-based food. Reducing food wastage via the united efforts of consumer, retailer and producers, to mitigate the global climate change, reduce the natural resources use, and feed more population without extra production increase. In addition, develop new crop and animal varieties, and adopt rational irrigation and fertilization, as well rearing management, help to increase the food production and the resources utilization efficiency**.**

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# Chapter 2

# Climate Change and Food Security

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## Contents

## 2.1 TEMPERATURE AS A BASIC INDICATOR OF CLIMATE CHANGE

Climate is the state of the atmosphere in a given period of time and in a specific region, *e.g.* summer climate, desert climate, high mountain climate, etc. Natural and human produced vegetables and animals used for food production are strongly influenced by the climate. Therefore, its knowledge and possible change are of importance in present time, since climate influences food production for about 7.5 billion inhabitants, as well as its future evolution, considering that it is expected to increase at about 9.7 billion inhabitants by the middle of this century (UN Population Division, 2017).

Ambient (air) temperature is the main atmospheric variable that determines a given climate. Consequently, its behavior along the past and future times is of great importance. Considering the annual evolution of Northern Hemisphere temperature data in the last millennium presented by Jones and Mann (2004) and obtained from the analysis of different sources (tree rings, etc.), Piacentini and Mujumdar (2009) were able to determine the slopes in the period 1000-1900 using a mathematical approximation called the Fast Fourier Transform technique (see for example, Walker, 1996). They obtained a small negative trend of -0.02 °C/century. Around this last year (1900) and mainly due to the propagation all over the world of the Industrial Revolution that was born in UK about the year 1750, a strong modification in sign and value of the trend occurs, with a figure of0.6°C/century for the 20$^{th}$century.

**Figure 1** describes the time evolution of the annual global ambient air temperature near surface as a mean of measurements done in the period 1880-2016 by thermometers of the National Weather Service meteorological stations, and more recently of satellite thermal sensors. The data, provided by NASA Goddard Institute for Space Studies (GISTEMP Team, 2018, see also: IPCC, 2013), are very near those of other three independent statistical analysis done by the following prestigious Institutions/Organizations of the World related to climate: National Oceanic and Atmospheric Administration (NOAA) of United States, Meteorological Office Hadley Centre of Great Britain and Japan Meteorological Society. This Figure 1 shows that, from the reference period 1880-1900 up to the average period 2012-2016, the mean global air temperature increased about1 °C, with the largest contribution to this increase, of about 80%, coming from the last decades (1970-2016).

The World Meteorological Organization (WMO) in its 2017 Report (WMO, 2018) presents similar results: *Global mean temperatures in 2017 were 1.1 °C ± 0.1 °C above pre-industrial levels. Whilst 2017 was a cooler year than the record setting 2016, it was still one of the three warmest years on record, and the warmest not influenced by an El Niño event.*

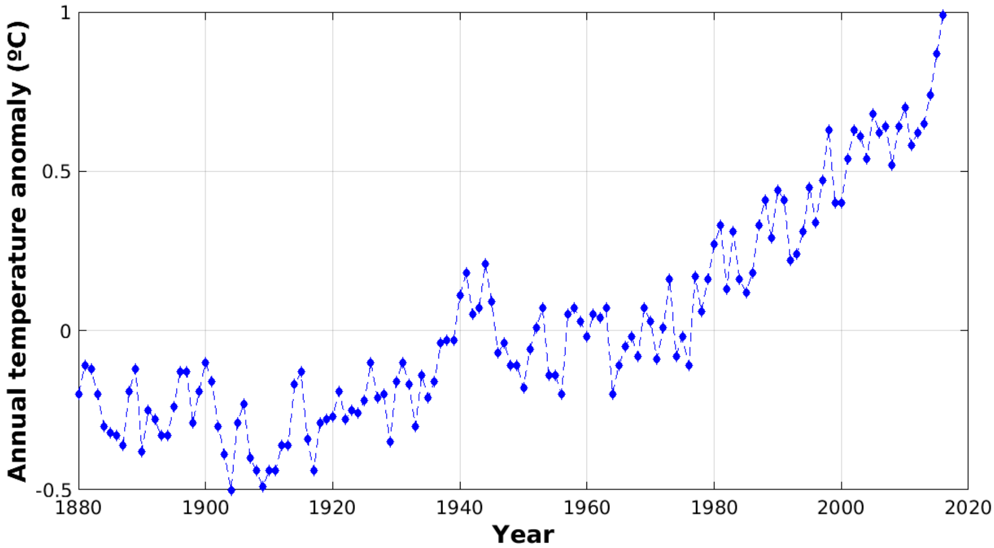


**Figure 1:** Time evolution of the annual mean global air temperature near surface done by thermometers of National Weather Service meteorological stations and more recently by satellite thermal sensors. Source: Based on data collected by NASA Goddard Institute for Space Studies, 2015 (Hansen, 2010; GISTEMP Team, 2018). Available at: https://www.giss.nasa.gov/research/features/201501_gistemp/)

One of the climatic phenomena that influences significantly the ambient temperature worldwide is the El Niño event, which is part of a larger event called ENSO (El Niño Southern Oscillation) that includes also La Niña event. The first one is an anomalous heating of the Tropical Pacific Ocean surface water that usually can produce large rains (and associated floods) in some regions of the World and droughts in others, affecting significantly food production. La Niña is the reverse situation, an anomalous cooling of the same waters, producing also reverse climatic situations. For example, in the very fertile Humid Pampa of the Central Argentina region, the Strong El Niño event of 2015-2016 produced an excess of precipitation with floods of the Paraná and other rivers; but in the last part of the year 2017 and the beginning of 2018, a Moderate (and even a Weak) La Niña determined a significant reduction in soybean and corn production (NASA report, 2018).

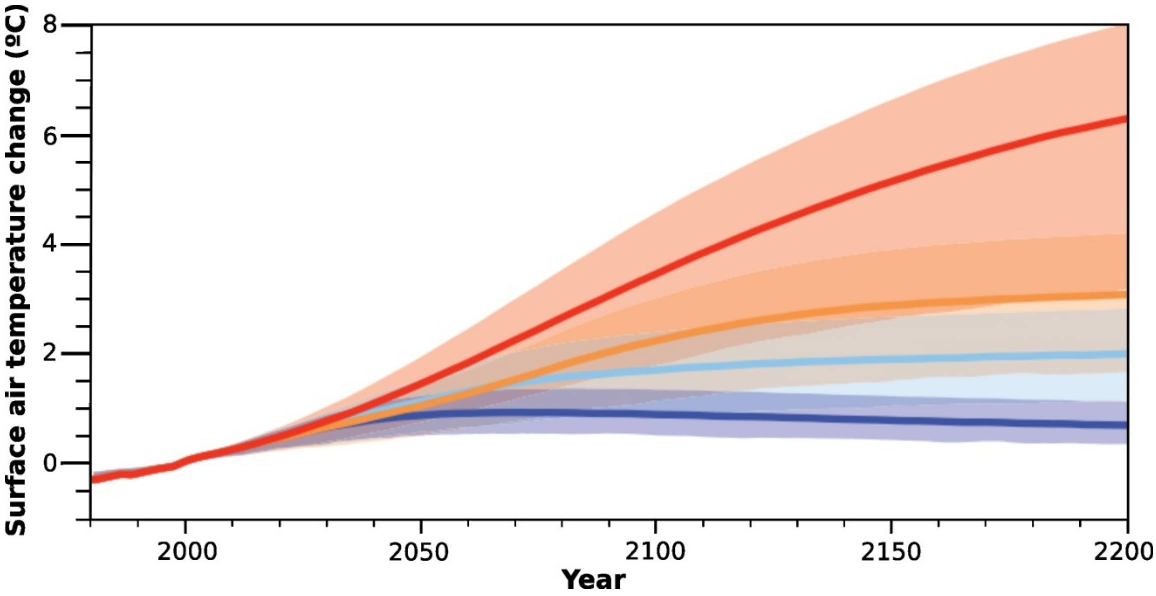


**Figure 2:** Projected global mean (near) surface temperature change during the period 2000-2200, for the different scenarios of radiative forcing (the net energetic atmospheric balance directly related to greenhouse gases emissions): RCP2.6 (blue), RCP4.5 (light blue), RCP6.0 (orange) and RCP8.5 (red). The color bands correspond to the uncertainties due to the combination of different model calculations. Source: First part (from 2000 up to 2200) of Figure 12.43 of the IPCC Working Group 1 Report (Collins et al., 2013, in particular: https://www.ipcc.ch/report/graphics/index.php?t=Assessment%20Reports&r=AR5%20-%20WG1&f=Chapter%2012)

The future temperature evolution is unknown, but it is possible to propose different scenarios based on the way humanity will react to the global warming problem. A systematic analysis of a large number of results has been made by the United Nations Intergovernmental Panel on Climate Change (IPCC) that is integrated by specialists all over the World. The main scenarios of Representative Climate Pathways (*RCPx*) for four different *x* values of the *radiative forcing* (the net energetic atmospheric balance directly related to greenhouse gases emissions) are: RCP2.6, RCP4.5, RCP6.0 and RCP8.5. The temperature time dependence forecasted by IPCC in the last report (IPCC, 2013) is represented in Figure 2. The trend in each scenario goes toward different final increase values, with respect to the reference period (year 2000) at the end of the present century (2100): *1.0 °C* for the optimistic scenario RCP2.6, 1.75 °C for the low intermediate RCP4.5, 2.31 °C for the high intermediate RCP6.0 and 3.50 °C for the pessimistic RCP8.5. At the end of the next century (2200) similar data are: *0.75 °C* for the optimistic scenario RCP2.6, 2.04 °C for the low intermediate RCP4.5, 3.13 °C for the high intermediate RCP6.0 and 6.33 °C for the pessimistic RCP8.5.

In **Figure 2** and in a similar way as was done in another work that relates climate change with health risk (see item 1.4 of the present Chapter and also, Piacentini et al, 2018), we extended the analysis to the 22nd century, since people that was born at the beginning of the present century (like the Z and T generations) will have a life expectancy extending to the final decades of the present century and even to the next century (Office of National statistics/UK, 2016).

Another way to predict the future is to extrapolate the past behavior through a mathematical approximation curve, as was done by Piacentini (2018). In this case, the result at the end of the century is 5 °C, which is an alert to modify this behavior, since the negative impacts would be significant (IPCC, 2014). Even increases in temperature larger than 1.5 °C but lower than 2 °C, with respect to pre-industrial era, can produce significant effects in the planet, as reported recently by the IPCC (2018).

## 2.2 MAIN FACTORS RESPONSIBLE FOR CLIMATE CHANGE

Now that enough scientific information is available of the fact that the global warming is real, it is necessary to analyze who are the main responsible of climate change. The most detailed and comprehensive analysis has been done in the last IPCC Report (IPCC, 2013), through the introduction of the concept of *radiative forcing* of the atmosphere: the net balance of the incoming solar radiation (that is the main heating source of the Earth atmosphere, ocean and land) and the outgoing radiation (sum of the reflected solar radiation and the Earth emitted one).The corresponding values for the main components of the atmosphere that contribute to global warming are (in decreasing order of importance):

- *Carbon dioxide* (*$CO_2$*, produced mainly by fossil fuel combustion and non-retired from the atmosphere due to deforestation and other areas with lack of vegetation) are, in units of irradiance or intensity:*1.68 $W/m^2$*.
- *Methane* (*$CH_4$*, generated mainly during cattle digestion, rice production, and emissions from open air urban landfills): *0.97 $W/m^2$*.
- *Carbon monoxide* (*CO*, a short lived gas in the atmosphere)*: 0.23 $W/m^2$*.
- *Halocarbons (HCFC,* included mainly in the new refrigeration systems, that replace the old ones, the *CFC*, that were responsible of the Ozone layer destruction, as detailed in WMO/UNEP, 2014): *0.18 $W/m^2$*.
- *Nitrous oxide* (produced mainly by land fertilization for increasing vegetables growing for food production): *0.17$W/m^2$*.
- *NMVOC* (non-methane volatile organic compounds, mainly produced by vegetation):*0.10 $W/m^2$*.
- *Solar irradiance change: 0.05 $W/m^2$*.

Therefore, the total positive contribution to the radiative forcing that heats the atmosphere equals to: 3.38 $W/m^2$. The atmospheric components that contribute negatively to the radiative forcing (so to global warming), cooling the atmosphere, are:

- *Cloud adjustments due to anthropogenic aerosols: -0.55 $W/m^2$*.
- *Allanthropogenic aerosol contributions:* They are mainly: mineral dust, sulphate, nitrate, organic carbon and black carbon. In this last case the

radiative forcing is positive (the only one with this characteristics) and equals to 0.6 W/m$^2$.
- *Albedo change due to human land use* (more solar radiation is reflected to the outer space if a forest is deforested, since the reflectivity of this radiation normally increases for bare land): *-0.15* W/m$^2$.
- *Nitrous oxides* (*NOx* with x = 1 or 2, mainly produced by internal combustion of fossil fuels in vehicles)*:- 0.15* W/m$^2$.

Consequently, the total negative contribution to the radiative forcing equals to:- 1.12 W/m$^2$, being the final net (positive) contribution: (3.38- 1.12) W/m$^2$ = *2.26W/m$^2$.*

We can see that the only significant natural contribution to the global warming through the radiative forcing is the increase in *Sun activity* (about this solar activity, see for example, Calvo, Ceccatto and Piacentini, 1995). However, it has only *2%*contribution to the total global warming, being the rest (98 %) due to anthropogenic activity (IPCC, 2013).

## 2.3 SCIENTIFIC EVIDENCE OF CLIMATE CHANGE

As already stated, climate is the state of the atmosphere in a given time interval, like the winter climate, the mountain climate, etc. During hundreds of thousand years the Earth climate was changing (see for example, Weart, 2018). However, for the first time humans had the possibility to modify the climate, starting in the Industrial Revolution, around 1750 and evolving mainly the last (20) century and in the first years of the present (21) century. Piacentini and Mujumdar (2009) determined that the main variable that characterize the climate, the ambient temperature, from the beginning of the last millennium (year 1000) varies very little, decreasing at a rate of -0.02 °C/century up to around 1900 and then increases suddenly, at a rate of +0.57 °C/century. The most plausible explanation of this behavior is the increase in the atmosphere of the so-called greenhouse gases (GHG) and the type of particulate matter called black carbon (IPCC, 2013; IPCC, 2018). From thousand years up to the beginning of the industrial revolution, these three gases evolved almost constantly in atmospheric concentration, but with the increase in population and consequently with the use of fossil fuels, the deforestation and expansion of food production and related waste, among many other contributions, they increased significantly. In particular, $CO_2$ that never overpassed 300 ppm during a period as large as 800000 years (Petit et al., 1999; Higgins et al., 2015) in April 2018 reached 410 ppm, as registered at Mauna Loa, Hawai, USA (SCRIPS, 2018).

An important series of data that gives a strong support to the increase of the ambient temperature due to human activity, are those of the Borehole project (NCEI, 2018)

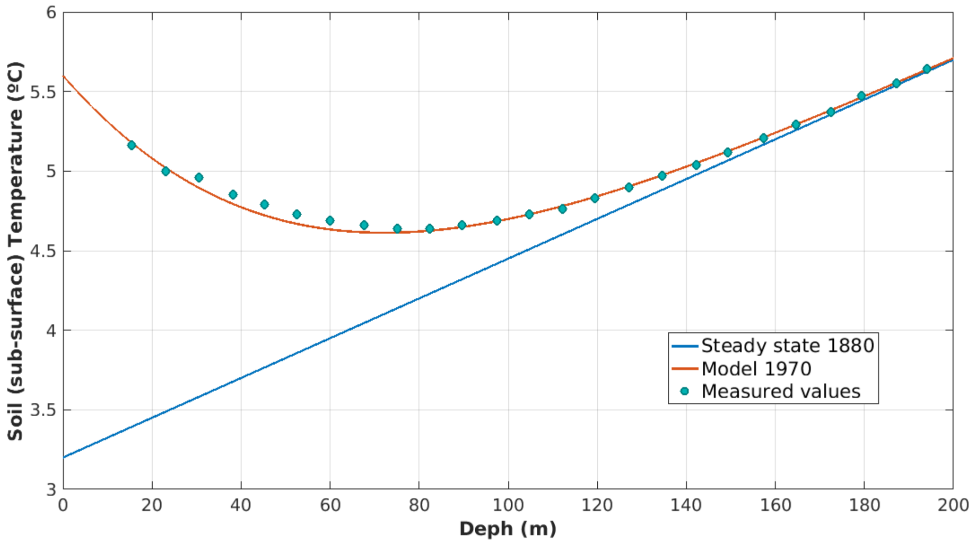


**Figure 3: Sub-surface temperature registered at the Kapuskasing, Canada, borehole site in 1970 (Cermak, 1971) (green points) and modeled employing the solution to the dynamic Fourier heat transfer equation (red curve).**

The asymptotic behavior given by the straight (blue) line corresponds to the 1880 stationary behavior, when global warming started to influence the boundary (surface) condition that collect the subsurface temperatures registered in different parts of the world at depths varying from near surface and hundreds of meters. Figure 3 displays the data obtained by Cemark (1971) in Kapuskasing, Canada, in the 20-200 meters of depth for the year 1970, in comparison with present model calculations.

We obtained these latter results considering that soil is a semi-infinite solid with boundary conditions at very near sub-surface, similar to the annual mean ambient temperature. The following solution to the dynamic Fourier heat conduction equation (see for example Carslaw and Jagger, 1959) was used to represent the sub-surface temperature, assuming as boundary condition, mean linear time dependence at near sub-surface

$$T(z,t) = \Delta T.\left(\left(1+\frac{z^2}{2st}\right).erfc\left(\frac{z}{2\sqrt{st}}\right) - \frac{z}{\sqrt{\pi st}}.exp\frac{-z^2}{4st}\right) \quad (1)$$

where:
*z*: depth being zero at surface and positive in the sense of the inner soil,
*T:* time (in years),
*s:* the soil diffusivity (equals to 1,06 mm/s$^2$ as given by Cemark, 1971),
ΔT: change in sub-surface temperature assumed to be due to climate change,
*erfc* function, that is related to the *erf* function in the following way:

$$erfc(x) = 1 - erf(x) = \frac{2}{\sqrt{\pi}}\int_x^{\infty} e^{-t^2}dt \quad (2)$$

We can see in Figure 2 that there is good agreement between the model calculation and the measured values, with a maximum difference between measured data and model calculation results in the range of only 0.1 °C, in all the analyzed soil region (up to 200 m depth). So, it is possible to determine, going back in time up to a linear (stationary) behavior asymptotic to the previous curve, at which year the soil started to be significantly affected by the air temperature increase, that introduce a modification in the boundary condition at surface. This year corresponds to 1880, which it is also in good agreement with the period at which the ambient temperature changed in slope (near 1900) (Piacentini and Mujumdar, 2009). In conclusion, the particular behavior of the sub-surface temperature (with a change of slope in the first part of the curve, between near surface up to around 160 m depth) can only be explained if a modification in the surface temperature is considered, in the sense of a positive increase, corresponding to global warming. This statement is also supported by the work of Beltrami et al. (2003) that analyzed spatial and temporal variability of ground surface temperatures in Canada in general and in the region of Kapuskasing, in particular.

## 2.4 IMPACTS OF CLIMATE CHANGE

The increase in temperature values is producing different impacts on the ecosystems and society. In this section we present impacts on non-food related subjects, since the food impacts will be described in the item 1.5.

***- Impacts on sea level rise and extreme events.*** The increase in ambient temperature, mainly in the Polar regions and at high altitudes (IPCC, 2013) and of the heat content of the ocean water is producing ice and snow meltings and consequently an increase in the sea level. Both contributions produced a level rise of near 20 cm from the industrial revolution to the present. Future projections are even a larger increase, between 0.26 cm (the minimum value in the optimistic RCP2.6 scenario) and 0.98 cm (in the pessimistic RCP8.5 scenario) by 2100 (IPCC, 2013b). Frieler et al. (2016) of the prestigious Potsdam Institute for Climate Impact Research (PIK) in Germany predicts that: "*even if greenhouse gas emissions were stopped today, sea level would continue to rise for centuries, with the long-term sea-level commitment of a 2°C warmer world significantly exceeding 2 meters*". Researchers of this Institute propose that sea level could rise even more than 130 cm by 2100 (PIK, 2016).

Concerning extreme events, Coumou and Rahmstorf (2012) analyzing world data of these types of events, concluded that "*many lines of evidence, -statistical analysis of observed data, climate modeling and physical reasoning-, strongly indicate that some types of extreme event, most notably heatwaves and precipitation extremes, will greatly increase in a warming climate and have already done so*".

***- Impacts on health.*** Higher temperatures determine the expansion of diseases to higher latitudes and altitudes, as is the case of Dengue (Liu-Helmersson et al., 2014). Van der Leun, Piacentini and de Gruijl (2008) and Piacentini, Della Ceca and Ipiña (2018), determined that even if solar radiation is the main responsible of skin cancers, ambient temperature increase can also produce an increase of these type of cancers, by considering statistical analysis of Skin Cancer Surveys in the USA.

***- Impacts on social problems.*** The increase in sea level is producing the flooding of low altitude coastal zones, that it is generating large human migrations, as is the case of Bangladesh in the Ganges delta (Karim and Nimura, 2008). Also, the migration of hundred thousand people from the Civil war region of Syria to Europe, has been explained, partially, by an intense drying period in a large fraction of the country induced by climate change (Kelley et al, 2015).

***- Impacts on ecosystems.*** The WWF (World Wild Foundation) in its 2014 Report (WWF, 2014), estimated that *Population sizes of vertebrate species, -mammals, birds, reptiles, amphibians, and fish-, have declined by 52 percent over the last 40 years. In other words, those populations around the globe have dropped by more than half in fewer than two human generations*. A fraction of this decline can be attributed to global warming. In the last (2018) Living Planet report, WWF states that: *The Living Planet Index tracks the state of global biodiversity by measuring the population abundance of thousands of vertebrate species around the world. The latest index shows an overall decline of 60% in population sizes between 1970 and 2014. Species population declines are especially pronounced in the tropics, with South and Central America suffering the most dramatic decline, an 89% loss compared to 1970. Freshwater species numbers have also declined dramatically, with the Freshwater Index showing an 83% decline since 1970.* It is also explained in the same report why Biodiversity matters: *Our health, food and security depend on biodiversity. From medical treatments to food production, biodiversity is critical to society and people's well-being.*

Two important publications analyze different impacts:

Mora et al (2018), consider that the emission of greenhouse gases is producing changes in different climate hazards, in particular, they *found traceable evidence for 467 pathways by which human health, water, food, economy, infrastructure and security have been recently impacted by climate hazards such as warming, heatwaves, precipitation, drought, floods, fires, storms, sea-level rise and changes in natural land cover and ocean chemistry. These findings highlight the fact that GHG emissions pose a broad threat to humanity by intensifying multiple hazards to which humanity is vulnerable.*

- NCA (US National Climate Assessment) published in November2018 its 4th National Climate Assessment. In particular, in its Volume II related to Impacts, Risks, and Adaptation in the United States, established that: *a) Climate change creates new risks and exacerbates existing vulnerabilities in communities across the United States, presenting growing challenges to human health and safety, quality of life, and the rate of economic growth, b) Without substantial and sustained global mitigation and regional adaptation efforts, climate change is expected to cause growing losses to American infrastructure and property and impede the rate of economic growth over this century, c) Climate change affects the natural, built, and social systems we* *rely on individually and through their connections to one another. These interconnected systems are increasingly vulnerable to cascading impacts that are often difficult to predict, threatening essential services within and beyond the Nation's borders.*

## 2.5 CLIMATE CHANGE INFLUENCE ON FOOD SECURITY

The generally accepted definition of Food Security is that stated at the Rome Declaration on World Food Security, in November 1996, by the United Nations Food and Agriculture Organization (FAO), which was refined in the FAO's State of Food Insecurity in the World in 2001: *"Food security exists when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food which meets their dietary needs and food preferences for an active and healthy life."*

This definition considers the four components of food security: food availability, food accessibility, food utilization and food system stability. When one or more of these components is uncertain or unreliable, the food system is considered vulnerable.

Some of the most important effects produced by climate change are affecting food systems at different scales (regional, local) and stages along food value chain, including food production and storage, food access and price stability. A great effort has been made to understand d the impacts of climate change on food production (Parry et al., 2004; Porter et al., 2014; Ali et al., 2017), but those impacts that might affect the aspects of food security not linked to production still present great uncertainties.

Moreover, the effects of climate change on the different dimensions of food security present great variation from one region to another throughout the world, and is expected to have a notable impact on patterns of trade between nations and development. Therefore, to evaluate the possibilities of adapting to climate change, the food system should be considered as a whole. The following items describe how climate change can affect the different dimensions of food security.

### 2.5.1 Food production and food availability

Food production is considered the basis of food security because it is a decisive step in food access. Most of the climate changes observed in different regions negatively affects local and regional food production. However, in some places, changes in climatic conditions favor the development of new crops and economic activities and, therefore, these changes can be considered positive. Anyway negative effects have been predominant with respect to the positive ones (Porter et al., 2014).

Agriculture, livestock and fisheries are all climate-sensitive economic activities and, therefore, they are likely to be affected by climate change. However, the possible impacts can be mitigated by the adoption of risk management measures and adaptation strategies that strengthen the productive systems and their capacity for recovery, which will also depend on the economic capabilities of each region.

## *Agriculture*

Agriculture is one of the most important activities for food security. In addition to producing food, agriculture is the main source of work for a large part of the world's population. According to data obtained from the '*World Urbanization Prospects: The 2014 Revision from the UN Population Division'* (United Nations, 2014), the world rural population comprises approximately the 45% of the total and the regions with the largest rural population are: central, north and west Africa (51%, 46%, 53%, respectively) and central, south and south-east Asia (57%, 63% and 51%, respectively). In these areas with greater dependence on agricultural production, the negative effects of climate change on agriculture will affect their main economic activity, increasing their vulnerability to food insecurity.

Concerning the contribution of Agriculture to the Greenhouse gases emissions (GHGe), Smith et al (2014; see also Ramankutty et al., 2018), in the 2014 IPCC/WGII Climate Change report, established that: *Globally today, agricultural management on already-converted lands is thought to make up ~13% of GHGe (5.0–5.8 GtCO2eq/year). Over one-third of this results from CH4 from enteric fermentation, ~15% from N2O emissions from manure and synthetic fertilizer application, and ~12% from CH4 in rice paddies.*

Among the effects that climate change can produce in agricultural production is the so-called *greenhouse fertilization effect*, which refers to the fact that higher levels of atmospheric CO2 stimulate plant growth (Erda et al., 2005). In temperate zones, assuming that $CO_2$ levels in the atmosphere reach 550 parts per million, it has been estimated that yields of crops with a lower rate of photosynthetic efficiency (C3 crops, i.e: wheat, soybean, alfalfa) could increase approximately by 10-25% and those with a higher rate of photosynthetic efficiency (C4 crops, i.e: maize, sugarcane, sorghum) up to 10% (Porter et al., 2014). However, given that this effect is also expected to facilitate the distribution and increase in the competitiveness of invasive weeds, it is not considered a positive effect.

The *greenhouse fertilization effect* is one of the parameters that present the greatest uncertainties in the models used to evaluate the impacts of climate change because there is limited experimental data on crop responses to increases in atmospheric $CO_2$. In addition, observed $CO_2$ increase is highly correlated with the main changes in technology, crop management and other factors that improved crop yield over time.

Regarding the increase in the mean temperature, projected impacts vary across crops and regions. For example, a moderate warming (1-3°C) in temperate regions is expected to benefit crop yields but to have negative effects in tropical and seasonally dry regions, in particular for cereal crops. All world regions would be negatively affected if the increase in average temperature exceeds 3°C (Porter et al., 2014). Extreme weather events frequency is expected to increase, and for example, abnormally high temperatures during short periods of time could significantly negatively affect crop growth and final yield (Wheeler et al., 2000; Innes et al., 2015). During the European heat wave of 2003, significant decreases in crop yields were observed, in particular, in the Central and Southern European agricultural areas. The increase of almost 6 ºC of the temperature, compared to the average in summer, seriously affected the potato, wine, maize and wheat production. The fall in cereal production in Europe was more than 23 million tons compared to 2002 (de Bono et al., 2004; Ciais et al., 2005).

Another of the expected consequences of climate change that can affect agriculture is the *precipitation gradual changes*. These changes imply modifications in the timing, duration, intensity of rain and snowfall. The changes observed vary according to the geographic location. An increase in the frequency and intensity of storms and floods has been observed in some areas. The agricultural area affected by floods increased in China, by 88% during 1970-2000 (Piao et al., 2010). In addition to direct flood damage, excess precipitation events led to excess soil moisture which affect crops in different ways: provides anoxic conditions, increases risk of disease and plant infections, delays agricultural processes (i.e., harvesting) because it makes the land inaccessible. Moreover, sea-level rises due to global warming will increase the risk of flooding of agricultural areas near the coastline.

An increase in rainfall can be considered a positive effect for agriculture in some areas. For example, in the Argentinean Pampas the increased precipitation led to the expansion of the agricultural frontier and an increase of up to almost 40% of the yield of soybean, maize, wheat and sunflower crops (Magrin et al., 2005).

On the other hand, some areas show a decrease in rainfall and, consequently, an increase in the frequency, duration and intensity of droughts. This will be particularly important in areas where production systems are based on rainfed agriculture. For instance, almost the 90% of Latin America farmed land is rain dependent (Vergara et al., 2014). Considering the fact that this region is the main source of sugar, soybeans and coffee (accounting for over 50% of worldwide exports; FAO, 2016), prolonged and repeated drought can cause a decrease in the availability of these basic foods in other parts of the world.
Other regions, such as the Asia-Pacific region, where a large part of the cultivated area is based on irrigation systems, would be less affected if there is a decrease in rainfall in this area (FAO, 2018). Expanding the use of irrigation in Latin America could be useful to ensure food production in this region, but this requires greater infrastructure and a large capital investment.

The expected greater *seasonal weather variability* and, as a consequence, changes in the start/end of growing seasons, will also have long-term implications on the viability of current agricultural systems and future food availability.

Since the space-time distribution of insects and plant pathogens is determined mainly by climate, an expansion of their geographic ranges to new warmer and more humid areas is expected, and as a consequence, greater vulnerability of crops to diseases, especially in the early stages of plant development (Bebber, 2015).

In summary, due to the changes in climate conditions, crop yield (as a global mean) is likely to be reduced and, consequently, cost of agricultural production (and food stuff) could increase. These changes will impact not only in large agro-industrial systems but also in smaller farm productive systems. Due to the fact that this last group presents in general less economic resources and resilience to face the impacts, the consequences for them would be greater. This is not a minor issue if we consider that in the current world there are around 500 million family farms which constitute the predominant agricultural model in developing countries and the largest provider of food for both developed and developing countries (FAO, 2014). For instance, in Latin America there are about 15 million family farms, covering almost 400 million ha which produce the 51% of the maize, 77% of the beans, and 61% of the potatoes consumed in the region (Altieri and Toledo, 2011).

### *Livestock*

Livestock products account for the 33% of global protein consumption and are an important agricultural commodity for global food security (Rojas-Downing et al., 2017). Livestock production systems are also important because they employ close to 1.1 billion people, mainly in the poorest countries in the world (Hurst et al., 2005). In many arid and semi-arid regions, they represent the only viable system of food production.

Livestock production is affected by climate change in different ways. Forage crops represent approximately 25 percent of the world's cropland (Nardone et al., 2010). Changes in production and quality of feed crop and forage due to the combination of increases in temperature, $CO_2$ and precipitation variation will directly affect the availability and quality of feed for animals. The length of growing season, which determines the period of available forage, is also an important factor for forage quality and quantity. Moreover, temperature and precipitation changes impact on water availability, animal growth, reproduction and health (Thornton et al., 2009; Henry et al., 2012).

Though some research has been conducted on the effect of changes in temperature in livestock (Nardone et al., 2010), there is still little information on the physiological, immunological and livestock behavior and its possible adaptation to climate change (Hoffmann, 2010). A better understanding of the animals’ biology (considering different varieties of livestock and species), and how they can be affected by changes in climatic variables and the indirect effects, such as exposure to heat stress or diseases, is necessary to predict impacts and develop adequate mitigation strategies.

### *Fisheries*

The described climate trends are also affecting freshwater and marine aquaculture production in different regions of the world (Cheung et al., 2010 and 2013). The abundance and distribution of harvested aquatic species are being negatively impacted and the trend is expected to continue. This fact threatens food security and nutrition especially in some tropical developing countries, and in communities that base their economy and nutrition mainly on this activity.

Will the expected higher yields in temperate regions (partially) compensate for lower yields in tropical regions? This is a complex issue; we must consider that many developing countries have a limited financial capacity to trade and a great dependence on their own production to meet the food needs of their population. Impacts on agricultural production will affect subsistence and access to food globally, and will also affect livestock production. Food security and the well-being of the population in areas with less capacity to cope with the effects of climate change, for example the poorest rural areas in developing countries, are at greater risk.

### 2.5.2 Food processing, storage and transport

Climatic effects in the storage and processing of the grains will be different according to the area in question. In those areas where humidity and precipitation increase, the grains will be harvested with up to 15% more moisture than is acceptable for a correct and stable storage (Porter et al., 2014). This will be a problem for crop drying and storage, and also increasing the contamination risk by microorganisms, incidence of pests, diseases and mycotoxins. Greater investments requirements to use new storage technologies to avoid this problem could lead to an increase in food prices.

Food transport and distribution is, as important for food security as production, and could also be affected by climate change. Food storage and processing technology has allowed the development of long-distance marketing chains, in which packaged food products are sent around the world at a relatively low cost and high speed. However, the increase in the frequency and intensity of severe climates (for example, storms) increases the risk of damage to transport infrastructure, impacting on the distribution of food and increasing the vulnerability of food supply chains.

On the other hand, there is a need to reduce the use of fossil fuels along the food chain. The expression '*food miles*' refers to the distance food is transported from its production center until it reaches the consumer. Food miles should be reduced as low as possible to reduce emissions of greenhouse gases, responsible for the global warming (see for example, Piacentini et al., 2015).

### 2.5.3 Food system stability: Marketing and retail

Food system instability is a result of the constant tensions between food system resiliencies and food system vulnerabilities (Jahn et al., 2018). Since climate is an important determinant of the price of food in the short and long term, the stability of the entire food system is at risk. The increase in the price of basic foods will affect mainly the food security of the poorest, which spend a large part of their income on basic food. For instance, in 2008, the combination of a general reduction of agricultural productivity and poor policy decisions, such as increased export restrictions applied by many countries and poor regulation of financial commitment in food markets, derived in a global food crisis which caused political, economic and social instability affecting both undeveloped and developed nations (Headey and Fan, 2008).

### 2.5.4 Food consumption and utilization

Food utilization is described as ‘the way in which the body makes the most of various nutrients in the food’ by the Food and Agriculture Organization (FAO, 2008) and can be considered the final step to adequate nutritional status. There are two main ways in which climate can affect food utilization: health and diet (Aberman and Tirado, 2014).

Health impacts involve the safety of food, water, and diseases and infections that can jeopardize the body's ability to absorb nutrients. Most of the projected diseases linked to climate change are related to diarrheal diseases and malnutrition. Diarrheal diseases do not allow the efficient absorption of nutrients. Some studies have found an association between the increase in temperature and the increase in episodes of diarrheal diseases (Singh et al., 2001; Azage et al., 2017; Horn et al., 2018). Also, during extreme rain events, there has been an increase in monthly reports of outbreaks of waterborne diseases in different parts of the world (Confalonieri et al., 2007).

On the other hand, the impacts on the diet imply changes in the nutrient content of the food. Increased concentrations of carbon dioxide may reduce the nutrient content of food crops, including protein, iron, and zinc content (Taub et al., 2010; Zhu et al., 2018). Moreover, nutritionally important minerals including calcium, magnesium and phosphorus may also be decreased their concentration under elevated $CO_2$ (Moretti et al., 2010).

Finally, the combined effects on health and diet increase the susceptibility of the population to diseases; this could cause a decrease in productivity and lead to greater food insecurity.

### 2.5.5 Conclusions

Climate change is affecting plant and animal biophysical factors, water and nutrient cycles and, consequently agricultural and other food production systems. There is increasing evidence about the negative impacts of climate change on crop yields, fisheries, and livestock. Moreover, other indirect impacts related to physical/human capital (i.e, roads, storage and marketing infrastructure, electricity grids, human health) might affect the economic and socio-political factors and, consequently, food access and utilization, threatening the stability of food systems.

While some countries in the temperate zone may be benefited by climate change (allowing the cultivation of new species, for example), most countries in the tropics and subtropics, which also tend to be the poorest and vulnerable, will be negatively affected.

However, it should be noted that there are still great uncertainties regarding how climate change will affect the supply, demand and trade of food worldwide. There is still uncertainty about what the magnitude and scope of climate change will be, how efficient will be the adaptation measures applied in the different regions, how technological development will help. It must be also considered that the social, economic or technical limitations of many countries can hinder the application of adaptive measures.

So far, the Paris Agreement of the United Nations, signed in 2015, is the largest global effort to limit climate change. However, some of the measures to achieve the Agreement objectives may not benefit the decline of global hunger. In order to limit the increase in global average temperature to below 2 °C above pre-industrial levels, the Paris Agreement proposed some measures related to land-use. These measures, that include the re-planting of trees in recently cleared areas, the increment of biofuels production, would take place in former agricultural lands and therefore cause a reduction in the space available for food production, which will lead to an increase in food prices and greater food insecurity (Fujimori et al., 2018). Fujimori et al. (2018) consider that the Paris Agreement should incorporate global food security policies in order to avoid adverse effects and suggest interesting measures: the increase in international aid from more developed nations, taxes on biofuels and the reallocation of income to the less developed nations so that they yield less income from agriculture. As can be seen, food security is a multidimensional phenomenon.

## 2.6 SUSTAINABLE ENERGY USE IN FOOD PRODUCTION

*Sustainable energy* is defined as the sum of *Renewable energy* (having a source that normally does not end its power supply) and the *Energy efficiency*, even if this last term actually it is not an energy, but a given reduction in its use, it can be considered as a *virtual source.*

### 2.6.1 Efficiency

The first step to sustainability is to consider an efficient use of a given resource (energy, water, soil, air, and ecosystem). We can define the resource efficiency coefficient as:

$$\eta_x = R_{used,x}/R_{total,x} \quad \text{or in percents: } \eta_x(\%) = 100*(R_{used,x}/R_{total,x}) \qquad (1)$$

being $R_{total,x}$ (= $R_{used,x}$ + $R_{loss,x}$) the total considered incoming or available resource of a type *x* introduced in a system (machine, vehicle, building, etc.), $R_{used,x}$ the useful resource and $R_{loss,x}$ the loss resource, as shown in **Figure 4**.

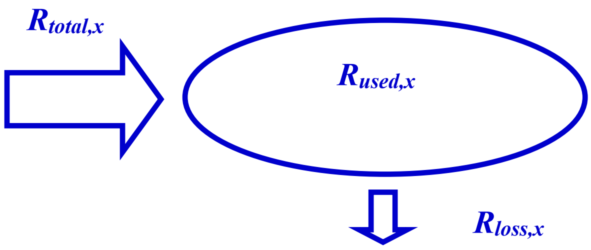


**Figure 4:** Schematic representation of a system with incoming (available) resource $R_{total,x}$ (energy, row material, water, etc.), used resource $R_{used,x}$ and loss resource $R_{loss,x}$

For example, in the case of the analysis of the energy efficiency of a truck diesel engine, a large fraction of the total incoming energy to the system ($E_{total,diesel}$) is loss ($E_{loss,diesel}$ = $0.7E_{total,diesel}$), resulting in a quite small efficiency, $\eta_{energy,diesel}$ $(\%) = 30\ \%$ . One of the main reasons of the large expansion of the electric vehicles in the last years (even trucks) is that an electric motor has an efficiency which can more than double the diesel one (see for example, Gustafsson and Johansson, 2015).

We like to point out that the energy efficiency can also be defined in another way, through the introduction of *indicators* (or indexes). One of the most common indicators is the quantity of fuel employed per period of time (liter of diesel/month, $m^3$ of gas/year, etc.).

### 2.6.2 Resource intensity

The resource intensity measures the use that it is done to a given resource (energy, water, raw material, etc.) per unit of reference, in a given period of time (usually a year). For example, in the case of electricity consumption, the Intensity is the total electric energy ($E_{energy}$) used annually ($I_{energy}$) in a building of a given total surface: $I_{energy}$ = $E_{energy}$/(year·surface), having units of KWh/(year.$m^2$).

It must be pointed out that this quantity permits to compare different systems, since the total resource (i.e., energy used annually) can be very high, but when referred to a given product (i.e., tons of grain produced with machines using this energy), is possible to realize if the system is working well. Resource intensity needs to be continuously decreased and resource efficiency on the contrary, needs to be increased.

### 2.6.3 Renewable energy

Renewable energy normally has a source that depends on natural supply: Sun, wind, water (river, sea), underground soil, vegetables (through

photosynthesis). Several energetic substances, if produced with renewable energy like hydrogen or compressed air, are also considered as a renewable energy source.
We will start analyzing the primary energetic source, solar radiation, that it is largely available in many parts of the world. The large deserts of the world and the zones at high altitudes normally have the large solar irradiation or insolation (in units of $KWh/m^2year$). Detailed maps and data on this variable can be obtained at the following addresses: NASA (https://power.larc.nasa.gov/data-access-viewer/, monthly data are given in the web page https://svs.gsfc.nasa.gov/30367), IRENA (International Renewable Energy Agency) (https://irena.masdar.ac.ae/gallery/#gallery) and Solargis (http://solargis.info/doc/free-solar-radiation-maps-GHI). An interesting and basic bibliography for these energy sources is the Open University (Great Britain) book: Renewable energy. Power for a sustainable future (Boyle, 2004). IRENA is also a nice source of information (www.irena.org).

### *Solar thermal*

One of the most common applications of solar radiation is the production of heat through solar collectors. In particular, solar water heating is a possibility for cleaning of vegetables devoted to food production. Solar heating can also be used for other applications, like: house inner climate, industrial processes, etc.

### *Solar photovoltaic*

Other application of solar radiation is its conversion to electricity, through the photovoltaic effect. Solar cells of different types are used for capturing and converting solar photons in electric charges. These last years, a notable expansion in the production and consumption of solar cells has been experienced, in the range of 35-40 % per year (Razykov et al., 2011; NREL, 2018). The efficiency of solar energy conversion to electricity employing solar cells has also a significant increase in many different types. In particular, the perovskite solar cells efficiency increases at a rate of near 2 % per year in the period 2013-2018, arriving at a maximum value of 23.3 % in 2018, even surpassing the Silicon multicrystaline solar cell (having a maximum efficiency of 22.3 %). The cost of the most commonly used solar cells (Silicon mono and multicrystaline) has decreased in around an order of magnitude (a factor of about 1/10) in only a decade.

Exceptionally large solar power plant complexes (in some cases photovoltaic alone and in others photovoltaic + thermal or only thermal) in the range of GW ($=10^9$W) are in construction at present in China (1,547 MW of power occupying a surface of 43 $Km^2$, at Tengger Desert Solar Park, in Zhongwei), India (Bhadla Solar Park with 2,255 MW of power and covering a surface of 40 $Km^2$ in Bhadla, Rajasthan state. This state is projecting solar power plants as big as 26,000 MW (http://projectreporter.co.in/prcontentdetail.aspx?Id=2627). The largest project at present is that proposed by Saudi Arabia that is projecting solar power plant complexes of 200,000 MW by the year 2030 (https://www.bloomberg.com/news/articles/2018-03-28/saudi-arabia-softbank-ink-deal-on-200-billion-solar-project).

*Wind*

Another way to capture energy from a natural resource is to use wind turbines exposed to rather windy regions (AWEA, 2018). The amount of power that can be obtained from these turbines depends in a direct way on the density of the air, the circle area defined by the length of its blades and most important to the cubic power of the wind velocity. So, if a region of the planet has double annual mean velocity than another region, the power to be extracted from the turbines increases by a factor of eight. In a similar way as for photovoltaic solar power plants, wind power plants are rapidly expanding all over the world.

*Water*

A hydroelectric power plant (a dam that intercept a river current and increase the altitude of the water level and consequently its potential energy) is considered a renewable power plant if it has a maximum power of 50 MW. Also, water power can be produced converting the energy of the tidal, waves and thermal gradient between the surface and inner parts at higher temperatures, like on salt lakes. Hydroelectric power plants of small scale are also possible without dams and water reservoirs through a systems similar to a wind turbine but used underwater, where the water flows act as the energy driver.

*Soil (or Geothermal)*

Since the soil temperature near surface has monthly mean values usually lower than ambient temperature (higher in winter time and smaller in summer time), it is possible to use the soil as an energy source for climatization of buildings/houses. It is based in the placement of tubes for heat transfer under the soil (usually called *geotubes)* at depth that goes from some meters to hundreds of meters, since more depth corresponds to more temperature (GEA, 2014).

*Bioenergy (biomass/biofuel/biogas)*

Biomass energy is produced by the combustion of vegetables in different forms: a) used directly in the form of solid fuels (wood, crop residues, etc), b) used indirectly transforming vegetables (or part of them) in liquid biofuels (called *bioethanol* and *biodiesel*) and c) by decomposition of organic material and transformation in gas (called *biogas*). However, care must be taken when using vegetables that can also be used for food production, trying to reduce to the minimum the competition energy vs food. For example, soybean is used intensively in Argentina for both applications, with only around 9 % of the oil material that can be transformed in biodiesel, much of the rest are proteins for humans and animals.

*Non-conventional fuels (Hydrogen, compressed air, electricity)*

Hydrogen, compressed air and electricity can be used as a clean energy source if they are produced employing renewable energy sources. They are very efficient and do not produce greenhouse gases, as conventional (petrol and gas derived) fuels. There are different applications of this type of non-conventional fuels, mainly in cars. A Japan car company (see https://ssl.toyota.com/mirai/fuel.html) is going in the hydrogen direction as a fuel, a French car company (see https://www.citroen.co.uk/about-citroen/concept-cars/c4-cactus-airflow-2l ) is promoting the compressed air plus conventional fuel, with a concept car consumption as low as 2 liter/100 Km and many car companies are developing electric cars (see for example https://www.whatcar.com/category/electric).

## 2.7 REDUCTION OF *FOOD MILES* AS A CONTRIBUTION TO CLIMATE CHANGE MITIGATION

Cities import most of the food they eat from outside their geographical boundaries. Sometimes, distances between the production centers and the markets or retail stores are considerably long. These distances traveled by food products are known as *food miles*.

After being produced in appropriate soils, transportation, processing, packaging and storage of food products contribute to the energy use. Moreover, if this energy is non-renewable (basically, oil, gas or coal), those processes are responsible for the GHG emissions that produce global warming (see item 1.1). Since distances are long, special acclimatization equipment are used for transportation, in order to preserve food for a longer period of time. Besides the most well-known gas, carbon dioxide, it must be taken into account that acclimatization equipment also emits hydrofluorocarbons (HCFC), another powerful greenhouse gas.

In several European countries, such as the Netherlands, 30% of the total greenhouse gases emissions are related to food consumption (W. Sukkel, University of Wageningen, Holland, 2012, personal communication). Similar trends can be expected in fast growing Southern cities, particularly in developing countries.

### 2.7.1 Calculation of energy consumption and $CO_2$emissions from the transportation of vegetable foods: the case of Rosario city, Argentina

Rosario is located in a region called Pampa Húmeda (32.51ºS, 60.44ºW, and 25 meters above sea level). The city has an estimated population of 1.000.000 inhabitants (year 2018), and along with the metropolitan area (Greater Rosario), this population rises to 1.500.000. The population growth in the last decades has been rather low, since the number of immigrant and the births were compensated by the emigrants, who moved to surrounding towns. The three vegetable foods that are most consumed in Rosario city, Argentina, are potato, tomato and lettuce. A small fraction of these foods are produced in the near peri-urban region and the rest comes to Rosario from long distances.

For example, potato is mainly produced in the region of Balcarce, Buenos Aires province at 650 Km from Rosario and a small fraction in the peri-urban site of Arroyo Seco, Santa Fe province (at around 30 Km from the city).
Following the work of Piacentini and Vega (2014) and Piacentini et al. (2014, 2015), in order to make a *food miles* analysis of the possibility to produce all these vegetables in the peri-urban (local) region, we consider three different scenarios:

- *Scenario 1:* current situation of exclusive use of trucks to transport the vegetable foods from Balcarce to Rosario.
- *Scenario 2:* multi-modal transportation, using trains to travel long distances and trucks (to and from train stations and production/consumption points) for short ones.
- *Scenario 3:* current situation of exclusive use of trucks to transport from Arroyo Seco to Rosario.

To obtain the energy consumed by transportation (trains and/or trucks) considered in the different scenarios and the associated greenhouse gases emissions (especially $CO_2$, since the other gases emissions are quite low if there is no acclimatization), we use the following coefficients to convert fuel volume to energy consumption: 36.6 MJ/liter and to $CO_2$ mass: 2.9343 $KgCO_2$/liter. They are given by International Sustainability and Carbon Calculations (ISCC, 2011).

Food miles results for the three scenarios are presented in Table 1, where it can be seen that the lower energy consumption and thus, the lower $CO_2$ emission can be found in Scenario 3, related to *local production*. The corresponding reduction of this Scenario 3, with respect to Scenario 1 (actual situation of food transportation by trucks in long distances) is 96%.

**Table 1:** Fuel energy consumption and carbon dioxide emissions, related to the transportation of the most consumed vegetables (potato, tomato and lettuce) in Rosario, Argentina.

| | **Total Emissions/year (Ton CO2/year)** | | | **Total Energy/year (GJ/year)*** | | |
|---|---|---|---|---|---|---|
| **Product** | **Present case**** | **Polymodal** | **Local production** | **Present case**** | **Polymodal** | **Local production** |
| **Potato** | 76030 | 34050 | 3140 | 6095 | 2641 | 252 |
| **Tomato** | 38860 | 23640 | 1413 | 2667 | 1895 | 113 |
| **Lettuce** | 90700 | 55120 | 6212 | 6865 | 4419 | 498 |
| ***Total*** | ***205590*** | ***112810*** | ***10765*** | ***15627*** | ***8955*** | ***863*** |

***GJ = $10^9$ J. **Long distance transportation.*

If the long distance transportation would be done by a multi-modal system (train+truck), as in Scenario 2, fuel and emission savings, (and, consequently, energy savings) compared to Scenario 3, would be of 51.2% and 55.2%, respectively (Figure 4). Moreover, this type of transportation favors traffic jam indicators, reduces car accidents and road infrastructure costs, among others.

**Table 1** show that potato is the vegetable than consumes the highest amount of energy, and, therefore, emits the highest amount of greenhouse gases, followed by lettuce, since it is necessary to have a large volume truck for a low density vegetable and at the end tomato. We like to point out that researchers of the Faculty of Agricultural Sciences of the National University of Rosario (placed in the peri-urban area of Rosario), determined that about 50% of the lettuce were disregarded at the end of the commercialization chain, due to improper techniques of packaging, transportation and storage.

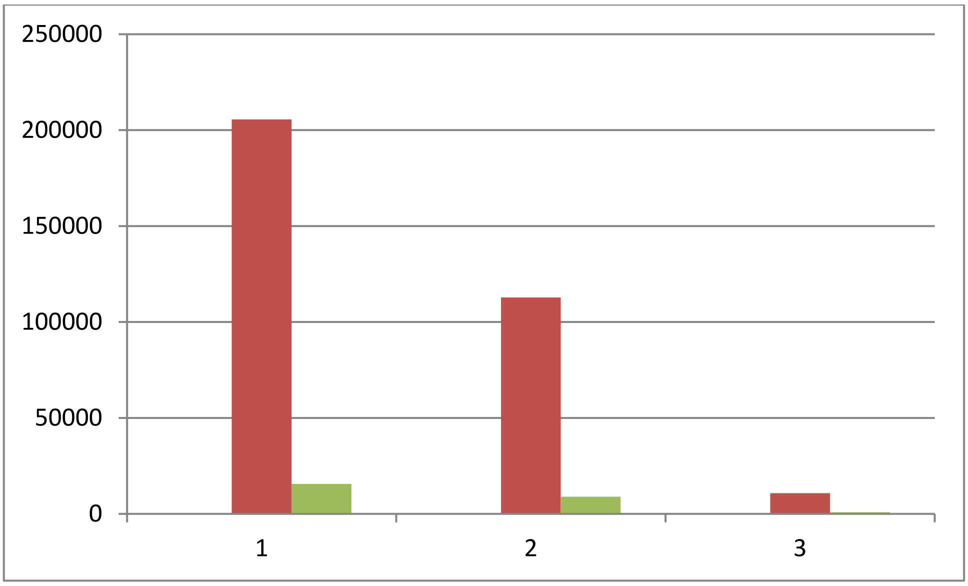


**Figure 4:** Fuel energy consumption (red bar, in GJ/year) and greenhouse gases emissions (green bar, in Tn$CO_2$/year) for transportation of the main vegetable foods (potato, tomato and lettuce) consumed in Rosario per year, considering different transportation systems: Present case (long distance transportation) (1), Polymodal (2) and Local production (3).

Similar analysis can be made considering other vegetables and other cities, all of which would result in a bigger contribution to mitigate climate change, just as other proposals like energy efficiency, renewable energy and materials uses (Piacentini y Della Ceca, 2017). It is important to mention that emission related to production itself (for example, mechanization, fertilization and other production practices) are similar for the local and distant production and that other advantages of local production include the strengthening of the food security and an increase in the food quality since they are harvested and delivered within a short period of time.

Piacentini and Vega (2017) obtained similar results regarding energy consumption and carbon dioxide, methane and nitrous oxide emissions when analyzing the replacement of synthetic nitrogen fertilizers with compost obtained from urban food waste.

In conclusion, a detailed analysis of energy consumption and polluting emissions related to food as well as to food waste can make a considerable contribution to the global effort to mitigate climate change and to improve the quality of life of marginalized urban and peri-urban population, mainly in developing countries, where there has been a massive migration from rural to urban areas. Besides all this kind of reductions, urban a peri-urban agriculture development policy improves food quality and creates stable jobs.

## 2.8 SOLAR DRYING OF FOODS AS A CONTRIBUTION TO CLIMATE CHANGE MITIGATION AND ADAPTATION

To preserve foods, drying of vegetables is a very interesting and usually economic and simple technique. It can mitigate the global warning by replacing the fossil fuels as an energetic source by renewable energies, and also it can contribute to adapt to this warming, since higher temperatures will deteriorate more rapidly the product that it is not stored at convenient (low) temperatures (consuming a large amount of electricity) or that it is not reduced in its water content.

We present in two solar dryers, one devoted to the drying of fruits and the other to the grains.

### 2.8.1 The design and test of family solar dryers for food security

Dehydrating food is one of the oldest techniques used by man to maintain food for a longer time than in normal conditions. This technology allows decreasing the aqueous and microbial activity, while minimizing chemical and enzymatic reactions keeping bacteria and fungi growth under control. In order to get the correct dehydration, it is necessary to evaporate as much water content as possible, which can be achieved by delivering directly thermal energy (heat) to produce evaporation or indirectly by air circulation causing homogeneous dehumidification.

Solar energy can be used in a direct or an indirect form for food dehydration. In the direct form, food is exposed directly to the sun; some transparent material can be placed over them in order for preservation from the surrounding dust deposition and to reduce heat loss. As advantages, it can be mentioned low cost and almost no maintenance requirements. On the other hand, its main disadvantages are: the slowness of the process, its heterogeneity and the difficulty to control e ambient temperature.

The indirect form consists of two structures with specific well-differentiated functions. On the one hand the solar collector, whose main objective is to capture solar direct and diffuse radiation and to use this energy for increasing air temperature. This is achieved by circulating air between a transparent material and a sheet of absorbent material.

After the increase in temperature, air enters the second structure, the drying chamber, where it interacts with food, absorbs its water and returns to the environment. Air circulation can be by natural convection or through a blower in the entrance or exit of the drying chamber. One of the main advantages of this system is that it avoids exposure to direct solar radiation, so decreasing the possible for food degradation.

It is possible to control air flow and its maximum temperature, limiting the nutritional and gustatory degradation of some products sensitive to high temperatures. Among other advantages, we can mention the isolation of food products from possible environmental contamination (dust, acid rain, etc.), and the protection of food against rodents or other animals. Regarding to energy efficiency, indirect dehydration generally has a greater drying efficiency than direct dehydration. These advantages determined the present choice of the last type of solar dryer to be built and employed for apple dehydration in an experiment done at Rosario city.

### *Experimental wood solar dryer*

We present two indirect solar dryers, designed and built with variations in construction material, size and purpose for which they were designed. Chronologically, the *Experimental wood solar dryer* (Figure 5) was the first one to be built, serving as a base and experience to another series of dryers built later. In particular, in the last one, the wood structure was replaced by a metallic one.

### *Construction goal*

The main construction goal was to have a device that allows to experiment and test manufacture, operation and efficiency measures to be applied to the device. It was designed in such a way that it could be easily built, being able to be carried out in training courses or workshops with small farmers, students, etc. It is also intended to be of low cost, since common materials that can easily be obtained in the market were used. The dryer was built mainly with pine wood and painted black plate. This model of dryer was used as a basis to build others and also to perform measurements and experiments.

### *Dimensions and materials*

The dryer has a solar collector plate through which the ambient air overpasses and absorbs energy. Then, it passes to the drying chamber, where the food is placed in slices to be dehydrated. The collector plate is mainly built with 0.02 m pine wood boards. The base size is 1 m long, 0.54 m wide and 0.12 m height. As lateral woods are 0,02 m thick each one, it results in 0.50 m² of effective solar collection area. The base layer is made of wood and over it, a thermal insulation of expanded polyethylene of 2 cm is placed.

A pre-painted black corrugated metal sheet is fixed above it and finally a UV resistant polycarbonate is placed as a cover. The distance between the polycarbonate and the sheet is 5 cm, space through which the air circulates, increasing its temperature and decreasing its relative humidity. Thanks to the corrugated form, the air can also flow behind the metal sheet.

The drying chamber is a wooden box of 58 cm wide, 70 cm high and 38 cm deep. It is at a height of 60 cm from the floor. The upper face is 45 degrees' slope, generating a height difference of 20 cm between the front and the bottom of the drying chamber. The front and the upper face are built with galvanized sheet painted black to increase the solar energy gain. The other faces are made with 0.02 m pine wood boards brushed on both sides.

**Figure 5:** Experimental wood dryer

### *2.8.1.1 Experimental metallic solar dryer with photovoltaic electricity support*

#### *Construction goal*

The purpose of the construction of these types of metallic solar dryers was different from the motivations of the self-constructed wooden model. The metal dryer arises from a specific request by Eng. Raúl Terrile of the Municipality of Rosario, who was working in a project to promote Agro-ecology in small and medium farmers with their productive lands near the city.

Since the users were small farmers, the following requirements needed to be met:

- Resistance of materials and design against bad weather and wear,
- High level of dehydration capacity,
- High efficiency,
- Temperature control in order to preserve the products quality
- Off-grid energy self-generation
- Collector design to be easy to clean.

Consequently, it was decided to build metallic structure of iron structural pipes, covered with galvanized metal sheet and insulated with expanded polystyrene. Also, to limit the collector exit air temperature, in order to keep food properties, it was decided to put a temperature controller, used to measure and control temperature with a J thermocouple. The internal relay can directly switch a cooler with ON/OFF control. This increases air flow reducing thus its maximum temperature. The device is energized by a 30 W solar photovoltaic (PV) panel as can be seen in **Figure 6**.


**Figure 6:** Metallic dryer for small producers

*Dimensions and materials*

*-Solar collector plate*

The first layer is a plywood plate, of 0.94 cm wide by 1.16 cm long varnished on both sides. An expanded polystyrene plate 2 centimeters thick is mounted over it to isolate the collector plate and to reduce the lower face heat losses. The pre-painted galvanized metal sheet is then fixed with self-tapping screws. Then the polycarbonate sheet is mounted on the structure. A 4 cm space from the metal sheet to the polycarbonate allows air to flow and the "greenhouse effect" (heating of the air) occurs. The collector plate is finished with two pieces of folded metal sheet in a "C" shape that cover the side woods and protect the (**Figures 7-12**).

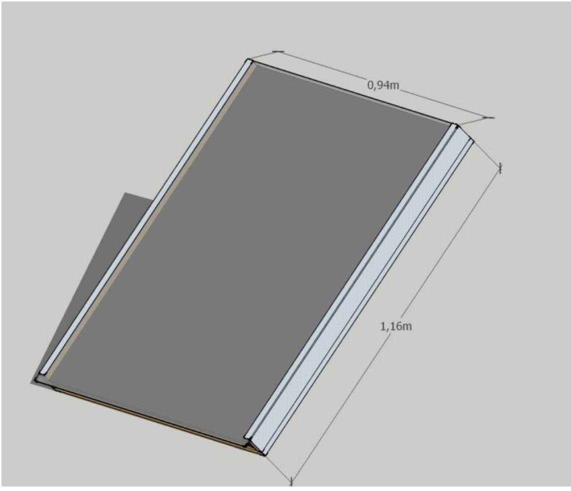


**Figure 7:** General image of solar collector plate with dimensions

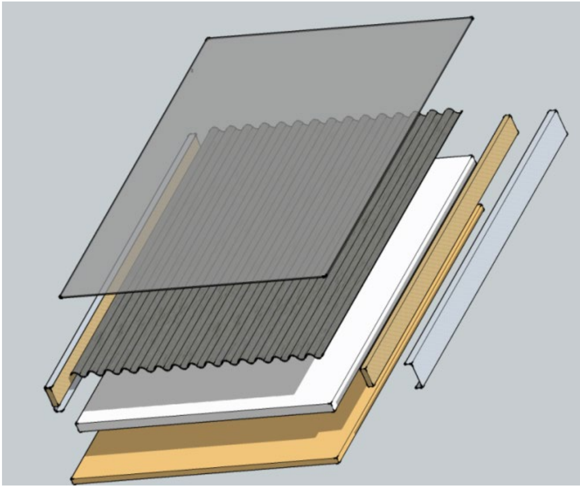

**Figure 8:** Different parts of the solar collector. From bottom to top, wood plywood, polystyrene insulation, pre-painted black metal sheet and polycarbonate

**Figure 9:** Solar collector plate

**Figure 10:** Construction detail

**Figure 11:** Construction detail of the dryer chamber

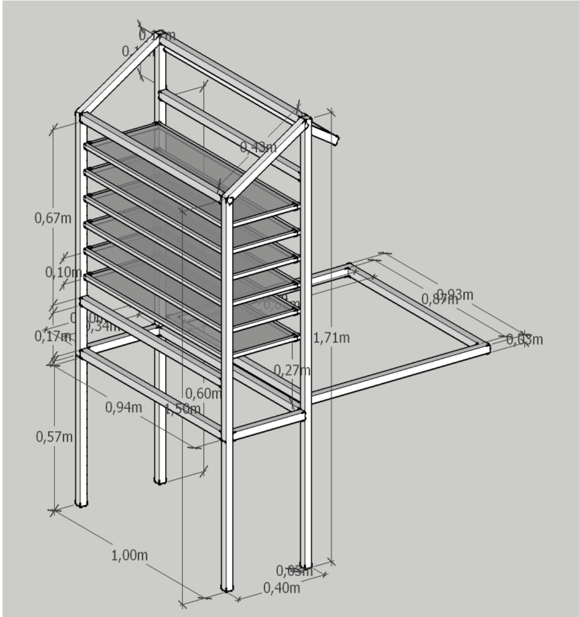


**Figure 12:** Dimensions of the chamber

*Quantitative design study*

*- Measurements*

The design goal of the solar dryers of this project is to dehydrate as many foods as possible, with the highest efficiency and at the lowest cost. Once the materials to be used in the design have been selected, the variable that will determine the cost of the dryer will be the size of the dryer.

To determine the dimensions of the dryer, two main variables must be taken into account. On one hand, the ratio between the size of the collector and the size of the drying chamber must be such that the collector has the capacity to absorb the energy necessary to dehydrate during the chosen time (1, 2, or more days) the moisture contained inside the food.

The total size can then be determined in two consecutive steps:

*a) Determination of the specific drying chamber volume employed per time interval*

We propose to obtain the specific volume of the dryer chamber that it is used in a given time interval (a day in the present case), as follows:

$$Specific\ dryer\ chamber\ size\ [m^3/day] = V_{sup} * Sup_{esp} * P$$

where:

- $V_{sup}$: Volume of chamber per surface of drying trays [m³/m²]

- $S_{esp}$: Specific surface: the surface occupied by each Kg of product in the drying chamber [m²/$Kg_{prod}$]
- P: The daily rate food production to be dehydrated [$Kg_{prod}$ /day]

$V_{sup}$ and $S_{esp}$ are constant characteristics of the chamber design and the type of product respectively, so the variable of the equation is the daily production to be dehydrated.

*b) Determination of collector surface*

On the other hand, it must be known the collector surface necessary to satisfy the energy demand. The surface will be determined by the following equation:

$$S_{colector} = \frac{P * H}{\eta * I}$$

where:

- I: daily solar irradiation, characteristic of the region and time of year [KWh/ (day.m²)]
- η: collector design performance [$Kg_{water}$/KWh]
- P: The daily rate production to be dehydrated [$Kg_{prod}$ /day]
- H: the product moisture content [$Kg_{water}$ /$Kg_{prod}$]

It must be noted that the only variable that can be optimized in a specific place, time interval, product and production rate is the performance of the collector, in other words, the ability of the collector to profit each KWh of energy received from the Sun, in evaporating water ($Kg_{water}$/KWh).

In order to optimize the design, it is necessary first to proceed by measuring and calculating its own characteristic constants: $V_{sup}$ and η. Then, to start selecting food products whose properties and dehydration processes are widely known to determine: $S_{esp}$ and H. So, knowledge of the initial situation of operation is obtained. This will allow recognizing the most easily variables to optimize and to have a quantitative starting point to analyze if the modifications introduced resulted in a better performance.

*-Collector performance*

The performance of the collector determines the mass of water to be dehydrated, according to the solar irradiance received during a given period of time and the surface of the collector. Therefore, the collector surface must be measured, the irradiance must be determined on a specific day, and the weight reduction of the product must also be measured throughout the day. We will also divide the measurement into hourly fractions to know the behavior of the collector in different conditions.

- Collector surface: 0.5 $m^2$
- Solar irradiance: Davis meteorological station, Vantage Pro2, of the Institute of Physics Rosario (CONICET – National University of Rosario, Argentina)
- Weight reduction sensor: Atma BC7103E electronic balance.

**Figure 13:** Left side, red apple before dray. Right side, red apple after dray

To determine the weight loss, we use the traditional method of measurement, which consists in removing the trays every certain period of time (1 hour). This form of measurement is quite good, but far from the optimal one, due to the need to open the chamber, with the consequent intervention in the drying process and the limitation in the frequency of measurements.

*Measurement results*

The solar dried food product was red apple (in pieces, **Figure 13**) and the measurements were taken on a particular clear day (24 July 2018), in the city of Rosario. The collector was located in a place where it received solar radiation throughout the day and also it was exposed to different wind directions, simulating normal field operating conditions.

**Table 2:** Total weight, net weight, weight reduction due to drying (water loss) and percentage reduction, for each of the two trays of red apples dried using the solar dryer, made in Rosario, Argentina, during a clear sky day (July 24, 2018)

| | Lower tray (1) | | | | Upper tray (2) | | | |
|---|---|---|---|---|---|---|---|---|
| | Total weight [g] | Weight without tray [g] | Weight reduction [g] | Per-centage reduction | Total weight [g] | Weight without tray [g] | Weight reduction [g] | Per-centage reduction |
| 10:08 | 871 | 482 | 0 | --- | 833 | 444 | 0 | ---- |
| 11:15 | 855 | 466 | 16 | 3.32% | 820 | 431 | 13 | 2.93% |
| 12:17 | 822 | 433 | 49 | 10.17% | 799 | 410 | 34 | 7.66% |
| 13:21 | 779 | 390 | 92 | 19.09% | 770 | 381 | 63 | 14.19% |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 14:21 | 741 | 352 | 130 | 26.97% | 746 | 357 | 87 | 19.59% |
| 15:17 | 718 | 329 | 153 | 31.74% | 725 | 336 | 108 | 24.32% |
| 16:23 | 694 | 305 | 177 | 36.72% | 700 | 311 | 133 | 29.95% |
| 17:25 | 674 | 285 | 197 | 40.87% | 682 | 293 | 151 | 34.01% |
| 17:56 | 672 | 283 | 199 | 41.29% | 676 | 287 | 157 | 35.36% |

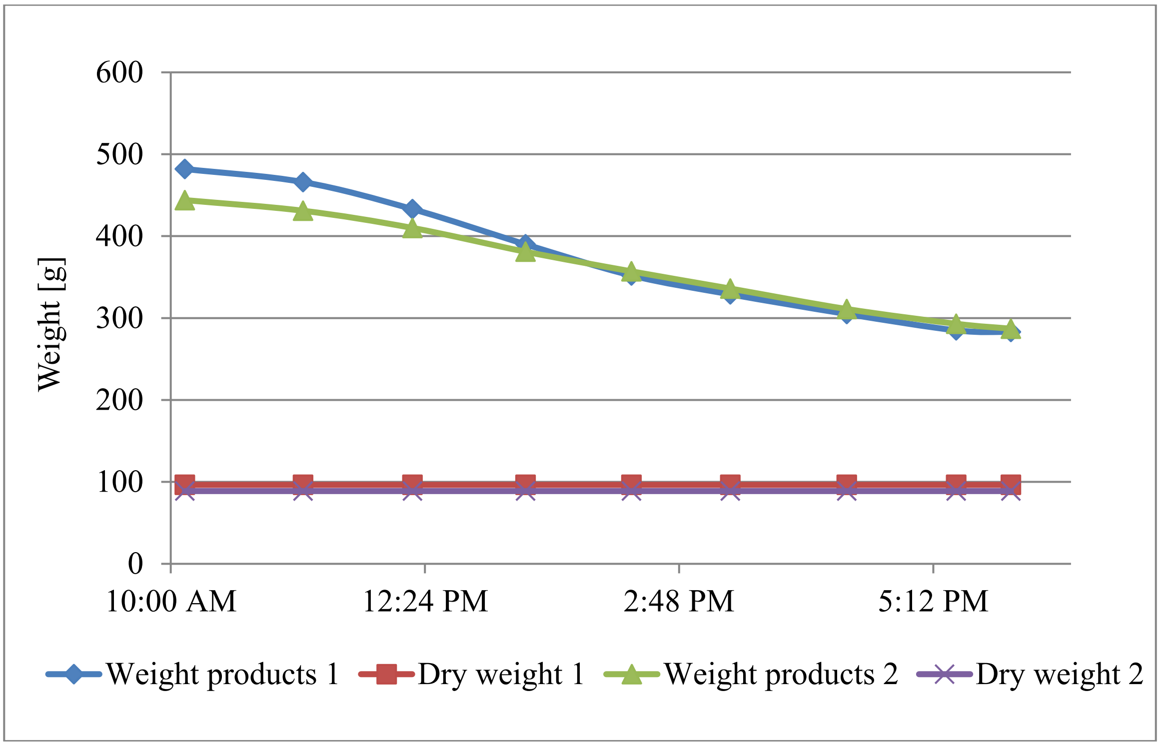


**Figure 14:** Weight reduction of red apple along the hours of the clear sky day (July 24, 2018), at Rosario, Argentina

**Table 2** and **Figure 14** show the weight loss due to solar drying of red apple, along the hours of the clear sky day (July 24, 2018).

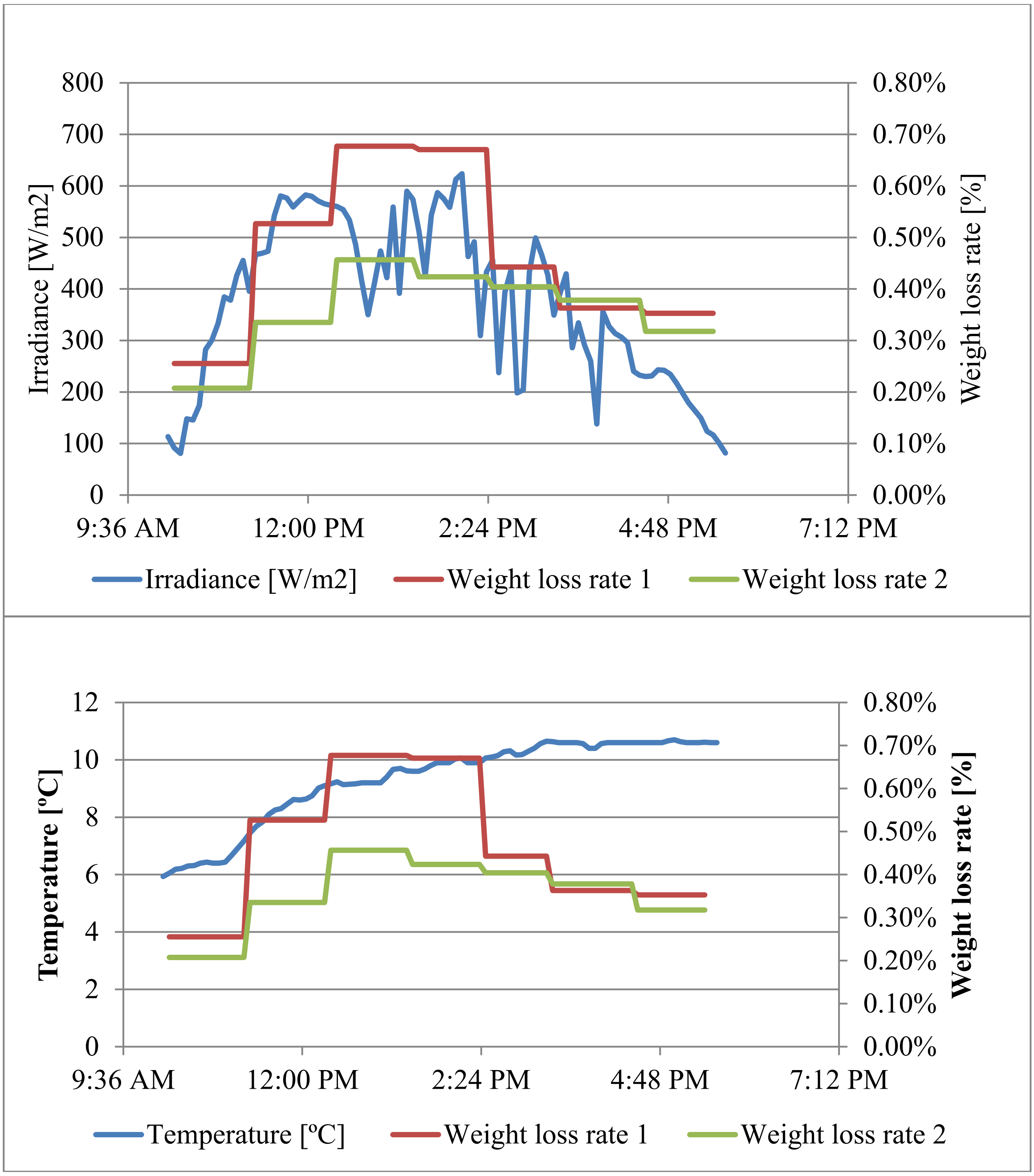


**Figure 15:** Solar irradiance (top figure) and ambient temperature (bottom figure) versus weight loss rate

The influence of solar radiation and of ambient temperature along the hours of the day is displayed in **Figure 15**. As expected, the weight loss rate is generally higher for tray 1 (due to its position in the dry chamber with respect to the incoming air) than for tray 2.

**Table 3:** Summary of the data giving rise to the total performance of the dryer.

| Hour | Weight tray 1 [g] | Weight tray 2 [g] | Average solar irradiance [W/m2] | Daily solar energy [KWh/m²] | Area [m²] | Perfor-mance of Tray 1 [Kg/KWh] | Perfor-mance of Tray 2 [Kg/KWh] | Total perfor-mance of the dryer [Kg/KWh] |
|---|---|---|---|---|---|---|---|---|
| 10:08 | 482 | 444 | | | | | | |
| 11:13 | 466 | 431 | 254.88 | 276.12 | 0.50 | 0.116 | 0.094 | 0.210 |
| 12:18 | 433 | 410 | 533.28 | 577.72 | 0.50 | 0.114 | 0.073 | 0.187 |
| 13:23 | 390 | 381 | 485.13 | 525.55 | 0.50 | 0.164 | 0.110 | 0.274 |
| 14:22 | 352 | 357 | 522.78 | 522.77 | 0.50 | 0.160 | 0.102 | 0.262 |
| 15:16 | 329 | 336 | 380.48 | 348.77 | 0.50 | 0.164 | 0.141 | 0.305 |
| 16:25 | 305 | 311 | 308.54 | 359.95 | 0.50 | 0.124 | 0.129 | 0.252 |
| 17:23 | 285 | 293 | 203.89 | 203.88 | 0.50 | 0.196 | 0.189 | 0.386 |

We like to point out that, the total dryer performance does not depend only on the incident solar radiation, but on other factors such as the thermal inertia of the collector and the ambient temperature, among others. However, averaging the obtained values, assuming that these factors will maintain the relative daily variation, a main daily value of 0.268 Kg/KWh is determined, that is, for each KWh received by the designed solar collector, 0.268 Kg of water will be evaporated.

*Comparison with a rather similar dryer tested in another climate*

To evaluate the performance of the proposed design of the *Experimental wood solar dryer* (that it is named from now on as *Rosario solar dryer*), a comparison is made of this dryer with the solar dryer developed and tested by Bharadwaz et al. (2017), of the Mechanical Engineering University, RSET, Guwahati, Assam, India (that it is named *Assam solar dryer*). The publication was chosen because the product to be dried and the construction characteristics are similar to the present solar dryer.

The biggest difference between the studied designs is that in the present studied device the air circulation is produced by natural convection, on the other hand the one of the Indian Group worked with an air blower. Another significant difference lies in the size, the collector plate of the Assam solar dryer is 1.7 $m^2$ compared to the present one, which is only 0.5 $m^2$. It is also important to highlight the difference in the time of year that the measurements were made, in the Rosario case it was a full winter day, with an average ambient temperature of 9.3 ºC and in the Indian dryer it was a spring day with an average temperature of 33.0 ºC.

The similarities are in that the two were built with common low cost materials and both also dehydrate the same product (apple). In addition, both are relatively small and are designed for family production scales.

**Table 4:** Comparison between the Rosario solar dryer and the Assam solar dryer

| | **Average collector temp (Cº)** | **Average ambient temp (Cº)** | **Initial weight (g)** | **Final weight (g)** | **Percentage weight loss** | **Solar collector area (m2)** | **Drying performance per solar collector area (g/m2)** |
|---|---|---|---|---|---|---|---|
| **Rosario solar dryer** | 36.8 | 9.3 | 926 | 578 | 37.2% | 0.5 | 696 |
| **Assam solar dryer** | 56.2 | 33.0 | 200 | 34 | 83% | 1.7 | 97.6 |

From the results displayed in **Table 4**, one of the conclusions that can be reached is that both solar dryers reduce a significant amount of water, the Assam solar dryer is 83% superior to the Rosario dryer that only achieved 37.2% of water loss. This difference can be explained since in the first case, the total amount of product to be dried was higher and the ambient temperature and collector area were lower. Comparing the collectors, both reached a similar temperature variation: 27.4ºC in the Rosario solar dryer, against 23.1ºC in the Assam one.

Another interesting coefficient that was introduced by Piacentini and Combarnous (1977) is the ratio between the water removed per day (at the same initial, intermediate or final drying days) and the collector area. The values of this *Drying performance per solar collector area* are given in **Table 4**, last column. For the Rosario solar dryer is: 696 g/($m^2$day), and for the Assam solar dryer it is lower: 97.6 g/($m^2$day).

In conclusion, the proposed solar dryers can be a good option for the storage of food and consequently, for improving food security.

### 2.8.2 The design and test of a simple solar dryer for grains

Grains can also be dried employing solar energy. Drying in not as rapid as that with a conventional high temperature dryer (more than 30°C -50 °C), since this last one can dry tons of grains in an hour. The solar dryer increases the ambient temperature by only several centigrade degrees but reduces significantly the relative humidity, contributing to the extraction of water from the inner part of the grain.

The Solar grain dryer was developed in the 1980 decade by the Solar energy group of the Institute of Physics Rosario (CONICET – National University of

Rosario). It is still working at the Experimental Farm of the Faculty of Agricultural Sciences, National University of Rosario, Zavalla, Santa Fe province, Argentina. It is made of a simple (bare) solar collector to heat the air and a barn (with a capacity of dozen of tones of grains) to preserve the grains (**Figure 16**). It has a bottom surface with hole giving the possibility to the air with low humidity to enter in the silo and in this way to dry the grains during several days. It was dried different type of grains, typically produced in the nearby region (soybean, corn, wheat, sunflower and even rice).

The main advantages of the bean solar dryer are: greater flexibility in the harvest and commercialization of the grain, better quality of the product (less cracking, higher germination rates and absence of burnt or contaminated grains), possibility of conditioning the grain in the place of the harvest, fuel economy, greenhouse gas emission reduction. In addition, the silo solar dryer is simple to install, has low maintenance and great robustness, easily adaptable to existing systems, can be used for other agricultural applications that require the production of heat at low temperatures, such as: air conditioning of greenhouses, place for vegetable processing.

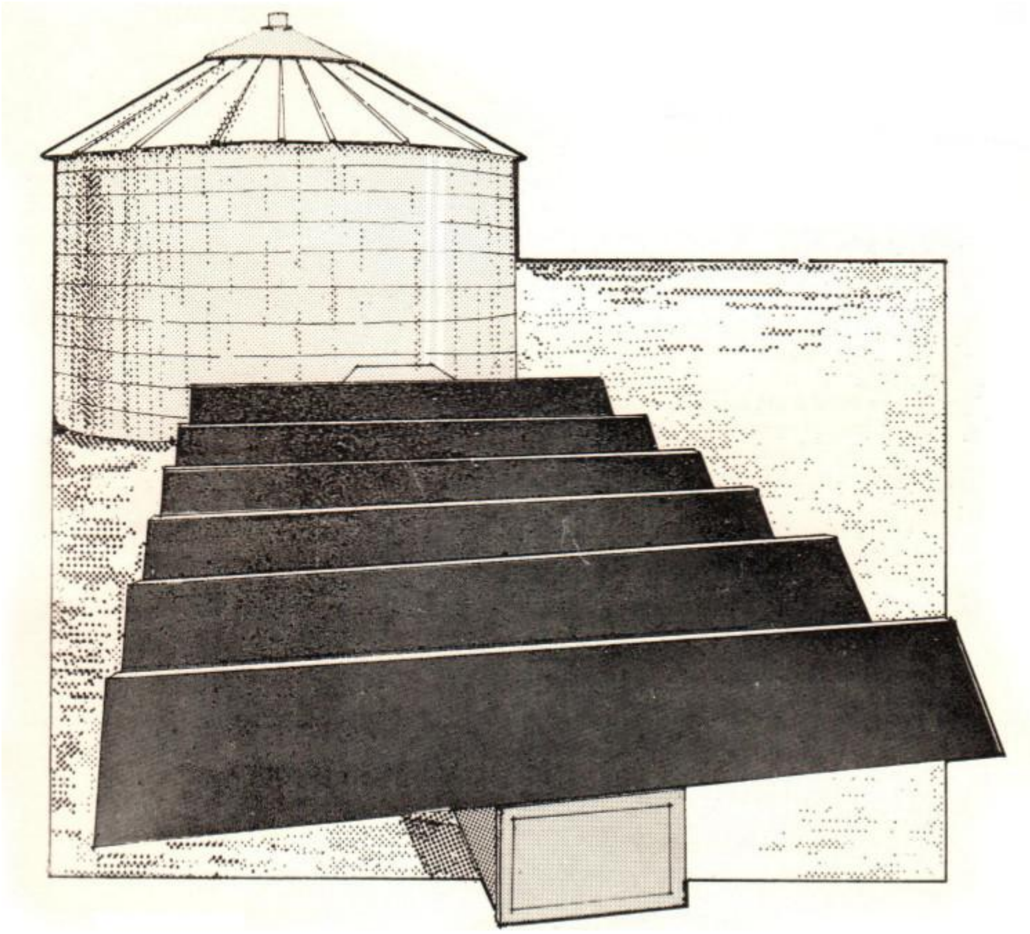

**Figure 16:** Schematic representation of the silo solar grain dryer developed by the Solar Energy Group of the Institute of Physics Rosario (CONICET – National University of Rosario) and placed at the Experimental Farm of the Faculty of Agronomical Sciences, National University of Rosario, in Zavalla, Santa Fe province, Argentina.

We like to emphasize that this solar dryer was built in years of the 1980 decade were Climate change and Sustainability were not considered as priorities. In an editorial guest in Drying Technology, Piacentini and Della Ceca (2017) proposed several sustainability criteria that would be needed to consider if a new silo solar dryer is to be built at present. Some of the criteria are the followings: i) materials to be used must be renewable or recyclable (mainly, steel and wood, but they need to be properly maintained, with periodic application of paint, avoiding in this way as much as possible, steel corrosion and wood degradation), ii) the electric motor that pumps the solar heated air into the silo must have the highest possible efficiency, iii) the solar collector and the air flow through the grains stored in the silo must be optimized, and iv) a life cycle analysis (commonly known as LCA) needs to be made, in particular, the *carbon* footprint needs to be evaluated and, eventually, the greenhouse gas emissions, compensated. As a conclusion, the possibility to dry grains employing a sustainable energy source (like solar) will improve food security, reducing grain degradation and at the same time contributing to the reduction of the emission of greenhouse gases.

## 2.9 COMPETITION BETWEEN FOOD AND ENERGY PRODUCTION USING PLANTS

Energy at affordable and stable cost over time is a basic requirement for the development of modern societies. Since the Industrial Revolution, there has been a steady increase in fossil fuels, mainly for industries during the early stages and for transportation from the first decades of the XX$^{th}$. century on. Nevertheless, environmental concerns that started during the second half of that century soon became a major part of the development agendas due to the strong relation between greenhouse gases (GHG) released to the atmosphere by transportation and industries' fuels and climate change (IPCC, 2014). Therefore, the new arousing paradigm focused on using renewable energy sources, those that can be replenished during human lifetime scale, such as solar, eolic (wind power), geothermal, and biofuels. Anyway, it should be kept in mind that bioenergy, burning wood, is the oldest energy source of mankind.

Among these types of energies, biofuels, including liquid (derived from biomass for transportation uses), gaseous (methane gas), and solid (wood, charcoal) (FAO, 2010), offer a full range of possibilities. In accordance with feedstock and transformation processes involved in their production, biofuels can be classified in different types or generations. First generation includes bioethanol from sugarcane, *Saccharum officinarum*, corn, *Zea mays,* sweet potato, *Ipomea batatas,*and other minor species;and biodieselfrom soybean, *Glycine max*, oil palm,*Elaeisguineensis,*and canola, *Brassica napus*, among others.

Lignocellulosic feedstocks as woods (short rotation coppices *Populus*spp.,*Salix* spp.) or perennial grasses (*Panicum virgatum*; *Miscanthussinensis*, *Miscanthus x giganteus,* etc.) are second generation biofuels (bioethanol or pellets that can be used for heat and power), while $H_2$ and biodiesel obtained from algae comprise third generation ones.Third generation biofuels remain at lab or pilot stages, facing still a lot of technological and economic issues such as nutritional content of culture media and its aeration systems, how to achieve stable growth rates, biomass harvesting systems and lipid extraction (Enamala et al., 2018; Raheem et al., 2018; Verma et al., 2018).

In order to obtain second generation bioethanol, sequential procedures must be followed after harvesting and transporting low energy density feedstocks: mechanical or chemical pre-treatment for removing lignin and exposing cellulose fibers, cellulose hydrolysis (saccharification), glucose fermentation, and bioethanol distillation. Each of these steps has different options (Aditiya et al., 2016) being thermal and chemical pretreatments those with the highest energy, environmental concerns (GHG emissions, chemical pollution due to acids or alkalis used for delignification, etc.), and costs. Therefore, though many studies showing high energy efficiency and GHG reductions (Kumar et al., 2012; Karlsson et al., 2014; Morales et al., 2015; Pourhashem et al., 2016), there are very few true commercial lignocellulosic biofuel industries. These technological challenges to be fulfilled are been driven by positive aspects of lignocellulosic feedstocks that already had been established: (i) net reduction of GHG while using them; (ii) they can be grown on marginal lands with no competition for agricultural land; (iii) as most of the grasses for biofuel feedstock have C4 photosynthetic metabolism, there would be no effect on biomass production due to high atmospheric $CO_2$ and drought (Oliver et al., 2009) predicted by IPCC climate models (IPCC, 2014).

In spite of controversies due to the fact that first generation biofuels feedstocks are being used as food or for animal diets (Hill et al., 2006; Carroll &Sommerville, 2009, Rull et al., 2016), there are a lot of sugar or corn bioethanol production, as well as soybean, palm oil and canola biodiesel industries. Therefore, some people claim that biofuels are one of the factors responsible for the increase in food prices (Rosegrant et al., 2008) though according to the high complexity of the systems involved (crops and the technological events improving yields, land use change, population increase fostering food demand, and governments mandates and subsidies in biofuels and renewable energies), there is still a lot of controversy on the matter (Chakravorty et al., 2012; Hochman et al., 2014). Therefore, Tomei&Helliwell, (2016) highlighted the importance of focusing on the multi-functionality of agriculture, rather than in the food vs. fuel dichotomy.

Bioethanol was initially used as a biofuel when internal explosion engines were invented and only decades later it was displaced almost entirely by naphtha or diesel when oil exploitation began. Brazil developed the bioethanol industry from cane after the oil crisis of 1973 and persisted from there on. Argentina began also with such a project, but it was abandoned as soon as oil prices fell and remained with fossil fuels as the main energy matrix components, in spite of some hydroelectric plants and two nuclear ones. In USA, 10% corn bioethanol blended gasoline started early in the ’70 decade of last century, it increased up to 15% for special engines. USA is the largest corn bioethanol producer, consuming *circa* 1/3 of the total corn production.

The interest in biofuels resurfaced in Argentina in the XXI$^{th}$ century for three reasons: (i) oil prices increase during the early years of the XXIth. century; (ii) the idea that the reserves of fossil fuels were running out, which was later invalidated at least up to the present time and (iii) the international concerns on GHG. In 2006, a Law was passed in Argentina ruling the Regime of Regulation and Promotion for the Sustainable Production and Use of Biofuels, including bioethanol and biodiesel produced from of agricultural or agro-industrial raw materials (mainly based on sugarcane and soybean oil, respectively), and organic waste generated biogas. One of the regulatory aspects is the mandatory blending of fuels: gasoline with bioethanol and gasoil with biodiesel.

Though it was introduced in Argentina during the first decades of the last century, the cultivation of soybean started from the 60's on, in the most important agricultural area of the country, the Pampean region. In a few years, it became a major crop, increasing its cultivated area and production from 1970 onward (**Figure 17**) and competing with corn for the best lands in the area. Initially it was not considered a major oil crop, due to its relative low oil content (*circa* 18%). Symbiosis of soybean with nitrogen fixing bacteria (Rhyzobiaceae), high protein figures of the grain, full grain demand of different markets triggered and high prices the expansion of the crop (MAGyP, 2018), but the area of the other major crop, corn, was not affected (**Figure 17**). This soybean expansion diminished mostly pasture land for dairy and beef production, displacing cattle raising to other areas of the country and triggered land use change: from rangelands and woodlands to agriculture.

If the intention is to analyze the food-bioenergy controversy in the case of soybean and corn in Argentina, in spite of the high soybean biodiesel steady increase (**Figure 18**), the analysis is very complex due to: (i) there is no food deficit in the country, in fact the total production could feed a population 10 times higher; what exists are problems of economic access; (ii) direct consumption of soybean in the human diet is very low in the country, most of which is exported; (iii) according to the oil extraction system used (mechanical or solvent), different by-products are obtained that can be suitable for human consumption after industrialization (soybean meal, rich in proteins) or for animal consumption (these same flours), dietary or nutraceutical supplements (lecithin) and others for industrial use. Therefore, the problems that the intensification of cultivation can bring at the national level would not affect the food supply, but to other processes such as ecosystem services (biodiversity, storage of carbon in the soil, water retention in the soil, pollination, etc.) (Aizen et al., 2009), mostly due to land use change (passing from woods, shrubs or rangelands to crop land) than to cropping itself due to the improvement of management practices with lower environmental impact than Western Europe, USA, New Zealand, China, or Japan farmers (Viglizzo et al., 2011).

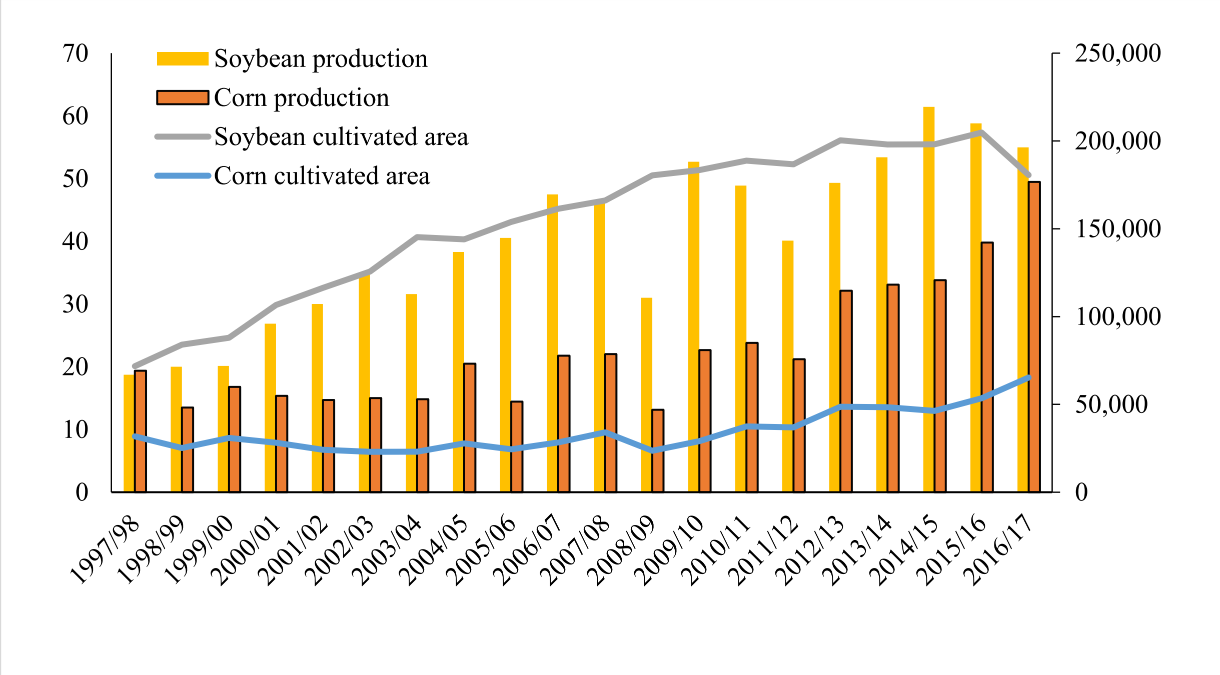


**Figure 17:** Soybean and corn production in Argentina: total production (Mg x $10^6$) and cultivated area ($km^2$) (1997–2017). Source: MGAyP (2018).

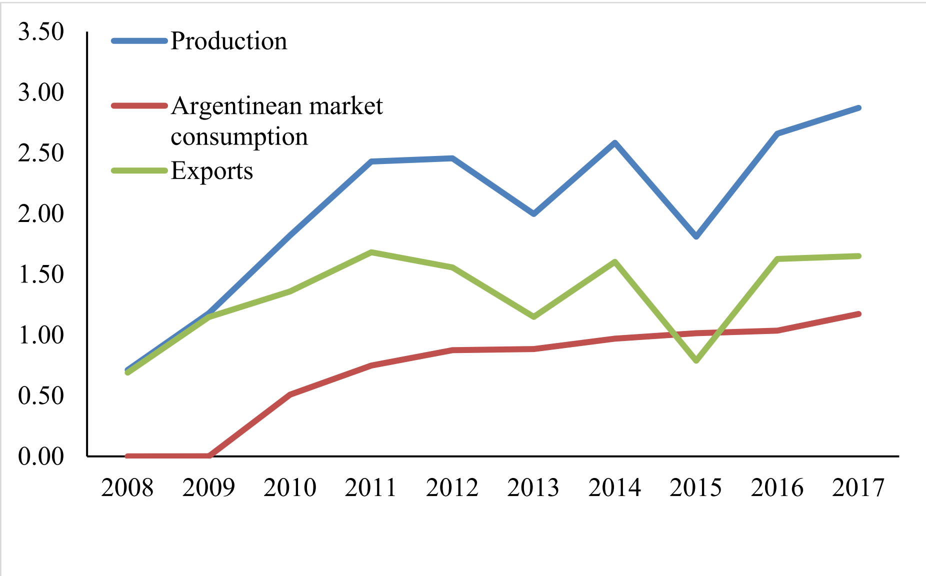


**Figure 18:** Total biodiesel production (Mg), Argentine market consumption, and exports. Source: INDEC (2018).

The same trend of no displacement of major crops (i.e., soybean vs. corn) is found in USA (Figure 19) as well as in Brazil (Figure 20). Nevertheless, though the data supports that on biomass basis the amount of crops being globally diverted to all industrial uses, including biofuels is not a significant amount (9% on biomass or calories basis, Cassidy et al., 2013), there are a lot of evidences suggesting a steady impact on food prices, with differences according to crops and countries (HLPE, 2013). An even in many countries, these figures of biomass diverted to biofuels can be higher than average (i.e.:

almost 40% calories in Brazil, Cassidy et al., 2013). Therefore, it can be concluded that considering the expected growth in human population and the increase in demand not only of food but of high energy demanding food (dairy, beef, fruits from distant markets), it should be convenient to increase funds in closing the technological gap for second generation biofuels and solar energy, which do not compete for land with food productions.

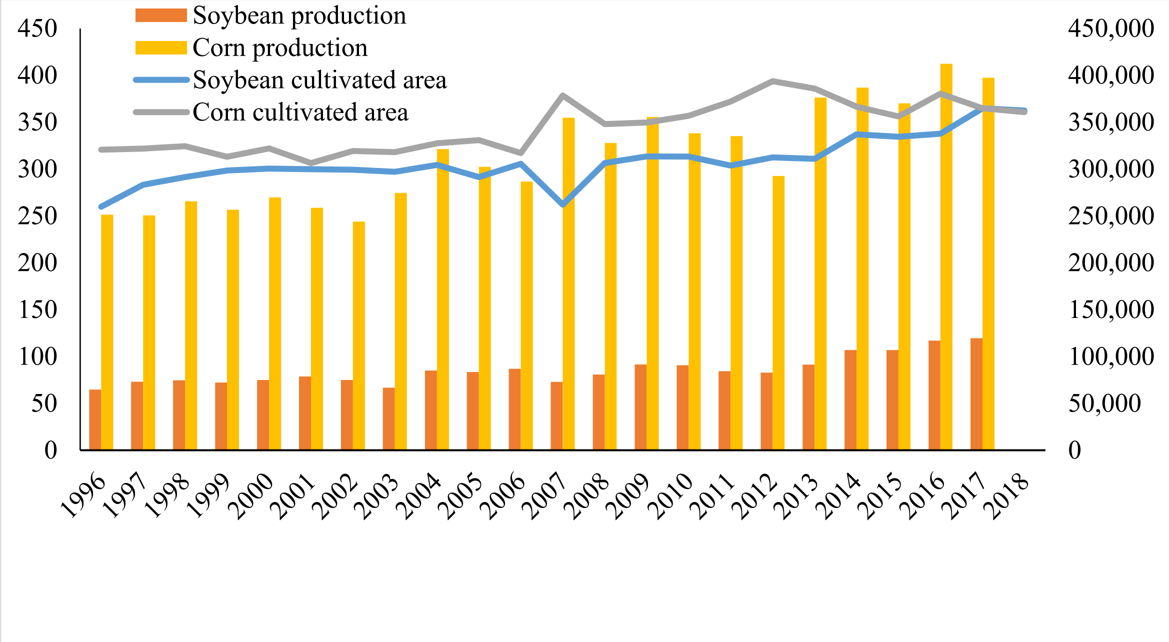


**Figure 19:** Soybean and corn production in USA: total production (Mg) and cultivated area (km$^2$) (1998–2017). Source: USDA (2018).

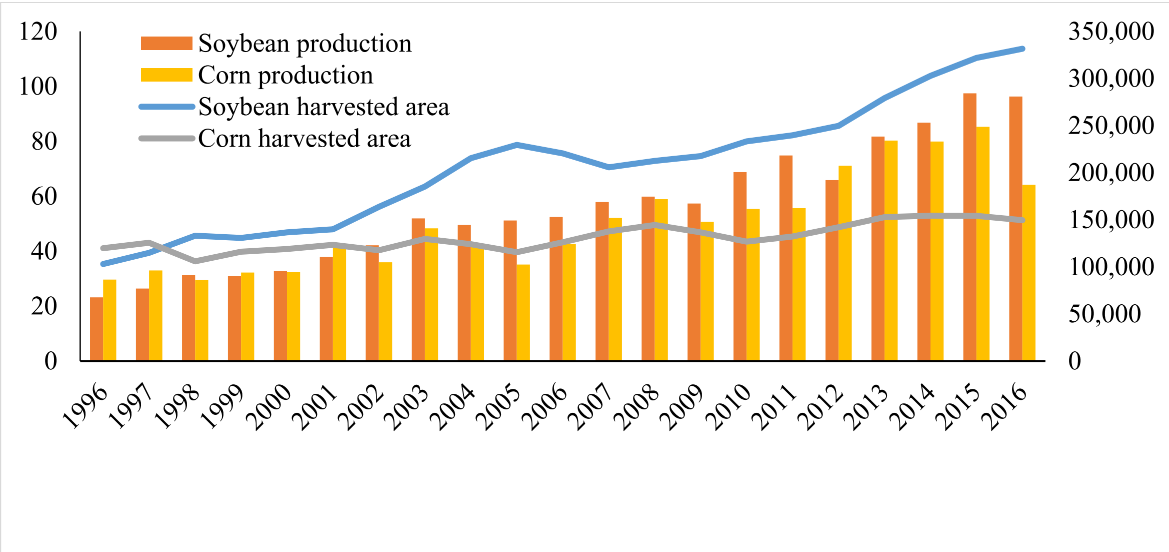


**Figure 20:** Soybean and corn production in Brazil: total production (Mg) and cultivated area (km$^2$) (1996–2016). Source: FAO (2018b).

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# Chapter 3

# Single cell proteins: Role in food security

*Shilpi Sharma, Khursheed A. Khan and Rachna Sehrawat*

## Contents

## 3.1 INTRODUCTION

Wastes may be defined as unwanted, not fully utilized materials which are discarded and considered as useless, i.e. the leftovers from production and consumption (Okonko et al., 2009; Ezejiofor et al., 2014), which are from numerous sources of households, industries, agriculture, mining, commercial, and other ventures, activities, and it poses serious environmental problem and it may lead to problem for humankind (Gaur et al., 2015). To achieve the balance between our economic problem and environment protection, giving emphasize on waste management is very important. It may be done by recycling and converting it into beneficial products by means of several technologies to achieve sustainable development.

As per data given by FAO, total amount of food wastage is around US dollar six hundred eighty billion in developed nations and US dollar three hundred and ten billion in developing nations (FAO, 2017).

- Quantity of waste generated by developed nations and developing nations is roughly the same i.e. six hundred seventy and six hundred thirty million tonnes respectively.
- The highest rate of food wastage is from F&V, roots or rhizomes.
- Globally the quantitative food losses and waste in line with each year different food commodities followed the trend as highest in rhizomes, fruits and vegetables (40 -50%) followed by meat and dairy (35%), cereals (30%) and least for oil seeds (20%).

Today, the trend in world is to convert waste into useful products or recycle waste product as much as possible by making low cost agro waste to value added food product by manipulation of microorganisms (Okonko et al., 2009). Detail statistical data regarding population and accessibility of inexpensive protein rich sources has been documented by FAO (Anupama and Ravindra, 2000). When traditional sources of protein became insufficient due to increasing population, it's crucial to identify sustainable, non-food protein sources (Mahan et al., 2008). Increasing concern about pollution that occurs due to industrial and agricultural waste has stimulated curiosity in conversion of waste into commercial valuable products like Single Cell Protein (SCP) by using micro-organism such as bacteria, yeast, mold and algae. Role of SCP in human nutrition got highlighted during times of war, and gained importance during the latter half of the 20$^{th}$century due to deficiency in protein sources and in order to cater the demand of day by day increasing population of the world. Apart from that countries with a large population (i.e. China and India) were doing lot of research to develop new SCP to deal with problems with malnutrition which shows current interest in single cell protein productions (Ritala et al., 2018).

At present, SCP is delivered from a predetermined number of microbial species, especially for utilization. The sources used for SCP generation for animal feed is broadly more extensive than that allowed for human utilization. Most recent patterns in research demonstrating the procedures created for the generation of SCP from economical leftover supplies produced from the food sector (beverages, confectionary, meat and poultry, dairy industries) as well as generated from directly agriculture and forests (Anbuselvi et al., 2014).

The name SCP was given by Carol and Wilson in 1966. “Pruteen” was the first commercialized SCP used as animal feed additive. It is dried cell mass of algae, fungi, molds, and bacteria grown in large scale over various range of substrate to produce protein biomass consisting of a mixture of proteins, fats, carbohydrates, Nucleic acids, minerals and vital vitamins (Couto and Sanroman, 2006; Singhania et al., 2009; Barrios-González, 2012; Aggelopoulos et al., 2014; Kosseva, 2013). Beside higher protein content (about 60-82% of dry cell weight), it has limited amino acids which are not present in foods developed from plant and animal origin (Ritala et al., 2018).

The protein which is obtained from the micro-organisms is easily available and have good nutritive value. Initially yeast was used for human foods but later the research was diverted in using it in animal feeds due to shortage of soy bean and fish meal across many countries (Panda, et al., 2017). Reports have shown, that companies have been working on feed generated from meat, poultry and fish sector using various strains of micro-organisms. The amount of agricultural and some industrial wastes such as citric waste, pineapple cannery effluent, cheese, fruits and vegetable waste, whey concentrates, stover of corn, rice effluent and polishing, soy molasses, hydrolyzed bagasse contribute a significant level of pollution in watercourse (Lanuzza et al., 2014, De Gregorio et al., 2002). Utilization of such materials as a potential substrate for SCP production is very important. Fruit or vegetable wastes contain mainly starch, fibres, soluble sugars and organic acids. Cellulose, most attractive substrate for SCP production but it is present in the complex form with hemicelluloses and lignin (Olena et al., 2005). In addition, most of the agricultural wastes such as rice bran, sugarcane bagasse, corn and other vegetable wastes are used as substrate (**Table 1**) and it reduces the cost of SCP production.

SCPs from microbial represents a potential future supplement source, since micro-organisms have higher protein content and can develop quickly on cheap raw material sources with least necessities. Citrus left-over has extremely lower protein content (6% on dry premise) and corns Stover are available in abundant, and an approach to utilize the waste material as substrate for production of SCP will facilitate in their effective utilization. But, regulatory considerations must be taken in care with the final end product constituent and should be in prescribed limits (Amini et al., 2014).

Due to increase in industrial activity of petrochemical, latex rubber and brewery industry all around the world, a large amount of organic chemicals has been discharged in watercourse. These chemicals have great quantities of hydrocarbon, chlorinated hydrocarbon and aromatic compounds such as aniline, phenol etc. Due to their toxicity, it may be harmful for the environment and can cause health risks. For the utilization of industrial wastewater, SCP can be produced by novel isolate Halophilic bacterium *Haloarcula sp.* and other microorganisms such as *Rhodopseudomonas palustris* and *Rhizospheric diazotrophs as shown in* **Table 2**.

## 3.2 DIFFERENT MICRO-ORGANISMS USED FOR SCP

### 3.2.1 SCP from Algae

Microalgae is rich in protein content (e.g., 60– 70%) which are delivered for human. It has fat (with omega-3 unsaturated fats), vital vitamins i.e. A, B, C, and E, as well as inorganic components and chlorophyll pigment (Gouveia et al., 2008) and nucleic content (3– 8%) is also low (Nasseri et al., 2011). Microalgae are right now utilized predominantly as enhancements, accessible in tablet, capsules. Algal SCP generation has confinements, requirement for warm temperatures and daylight, carbon dioxide. The accessible commercial products are derived primarily from *Arthrospiraplatensis*. *Spirulina*is, widely used algae and even astronauts take it to space during their space travel. Other algae used are *Chlorella* and *Senedessmus,*

### 3.2.2 SCP from fungi

A fungus generally contains 30–50% protein (Anupama and Ravindra, 2000). For production of biomass using solid state and submerged fermentation yeast is mostly utilized during World War I (Amini et al., 2014). Yeast may utilize soluble sugars and organic acids, produce biomass with higher protein content. It is expected that; it provides vitamins from the B-complex group. Since SCP produced using Fungi has low nucleic acid content so need for reducing the nucleic content is not required in the final product. Also if nucleic acid content is high then chances of kidney stones and gout also increase (Lipinsky, 1974). Another advantage of fungi is that it can be harvested easily which lower down the productions cost (Humphrey, 1975). Limitation for used of fungi as SCP is due to production of mycotoxins (Anupama and Ravindra, 2000). Presence of mycotoxins can cause allergic reactions and even death in severe cases so it is important to select and test the safety of the strain before utilizing it for production of SCP. The safety of *Y. lipolytica* and *F. venenatum* fungus is well documented for its utilization for SCP production and utilization into different food product development. The culture of *Aspergillus oryzae* or *Rhizopus arrhizus* were utilized for production of SCP due to their nontoxic nature (Anupama and Ravindra, 2000). Other filamentous fungi that have been used for production of SCP include: *Aspergillus fumigates, A. niger, A.oryzae, Cephalo sporiumcichorniae, Penicilliumcyclopium, Rhizopuschinensis, Scytalidumaciduphlium, Fusarium*and *Rhizopus* (Yousuf, 2012) grown in fermentation as a source of protein food. For commercial production of SCP, process utilizing yeast are more commonly utilized followed by bacteria (Geoffrey and Azevedo. 2009).

### 3.2.3 SCP from bacteria

Bacterial species are very nutritive because of their higher protein content with certain essential amino acid which is present in higher quantity as compared to algae and fungi (Singh, 1998). Bacteria may produce toxins which limit their use as SCP. Some pathogenic bacteria can be avoided. Although crude protein content is quite high (i.e. 80% of the total dry weight) but the nucleic acid content is also very high (15–16% total dry weight) which is not desirable as nucleic acis has to be removed to lower down the content within the prescribed limit (Adedayo et al., 2011). *Brevibacterium*, *Methylophilusmethylitropous*, *Acinetobactercalcoacenticus, Aeromonashydrophilla, Bacillus megaterium, Bacillus subtilis*, *Lactobacillus species, Cellulomonas species, Methylomonasmethylotrophu*s, *Pseudomonas fluorescens, Rhodopseudomonas capsulate, Flavobacterium species, Thermomonospora, Fusca Cellulomonas* and *Alcaligenes* are, most commonly used bacterial species for production of SCP (Trehan, 1993).

**Table 1:** Agriculture waste utilization for SCP production.

| **Substrate** | **Microorganism** | **Protein (%)** | **Type of fermentation** | **pH** | **Temperature (ºC)** | **Time** | **COD reduction** | **Drying temperature (ºC)** | **Reference** |
|---|---|---|---|---|---|---|---|---|---|
| Pineapple peel waste | *Candida utilis*, *S. cerevisiae, C. tropicalis* | 55.3 | Batch fermentation | 4.5 | 30 | 24hr | 88% | 105 | Mensah and Twumasi (2018) |
| Capsicum waste powder | *Candida utilis, saccharomyces cerevisiae* | 29 | Solid-state fermentation | 5 | 30 | 24hr | - | 105 | Zhao et.al. (2009) |
| Potato starch wastewater | *Candida utilis, C. eichhorniae* | 28.3-32.5 | SSF | 5 | 28 | 24hr | 74% | - | Bingnan et al. (2013) |
| Orange peels | *Saccaharomyces cerevisiae* | 30.5 | Submerged fermentation | 5.5 | 28 | 6 days | - | 105 | Aggelopoulos et al. (2014) |
| Cucumber waste | *Saccaharomyces cerevisiae* | 53.4 | SSF | 5.5 | 28 | 6 days | - | 105 | Kumar et al. (2012) |
| Potato starch | *A. niger, Candida utilis* | 46.09 | Solid-state fermentation | 6 | 30 | 12 h | 65-92 %. | 80 | Bingnan et al. (2013) |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Lemon pulp | *A.nigerandT.viride* | 24 | Slurry state fermentation | 3.7 | 30 | 5days | - | - | De Gregorio et al. (2001) |
| Banana peels | *Bacillus subtilis, Aspergillusterreus* | 18 | Solid-state fermentation | 7 | 35 | 24hr-5 days | - | - | Unakal et al. (2012) |
| Olive waste | *Candida krusei, Saccharomyces chevalierie and Saccharomyces rouxii* | 45 | Solid-state fermentation | 5 | 35 | 24hr | - | - | Gharsallah (1993) |
| Cheese whey | *K.marxianusand S. cerevisiae* | 30-60 | Solid-state fermentation | 4.5 | 35 | 48hr | 70% | 60 °C for 8 hr | Aggelopoulos et al. (2014) |
| Dairy wastewater | *Saccharomyces cerevisiae* | 28 | Solid-state fermentation | 3.5-4 | 25 | 4 days | 80 to 90%, | - | Mehrotra and Trivedi (2016) |
| Whey | *Kluyveromyces fragilis* | 91 | Solid-state fermentation | 3.5 | 35 | 48hr | 80% | 60 | Yadav et al. (2014) |
| Soy-bean hull | *B. subtilis, Candida tropicalis* | 56 | Batch fermentation | 5.5 | 21–36 | 30hr | - | 110 | Gao et al. (2012) |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Rice bran | Endophytic fungi, *Cladosporiumcla dosporioides* | 20 | Solid-state fermentation | 4.4-5 | 35 | 20 days | - | 105 | Jaganmohan et al. (2013) |
| Collagen | *Bacillus megaterium* | 36 | Solid-state fermentation | 7.0 | 34 | 12-16 hr | - | - | Bough, et al. (1972) |
| Prawn waste | *Beauveria bassiana* | 37 | Solid-state fermentation | 9.5 | 27 | 5 days | - | - | Suresh and Chandrasekara (1998) |

**Table 2:** Non-agricultural source of SCP production.

| **Waste material** | **Micro-organism** | **Protein (%)** | **Type of fermentation** | **pH** | **Temperature (°C)** | **Incubation period (days)** | **Reference** |
|---|---|---|---|---|---|---|---|
| Petrochemical Wastewater | *Haloarcula sp.* | 76 | Solid state fermentation | **-** | 42 | 5 | Taran and Asadi (2014) |
| Latex rubber sheet wastewater | *Rhodopseudomonas palustris* | 65 | - | 7.76 | 45 | 3-5 | Kornochalert et al. (2013) |
| Brewery wastewater | *Rhizospheric diazotrophs* | 55 | Solid state fermentation | **7** | 40 | **-** | Lee et al. (2014) |

## 3.3 UTILIZATION OF DIFFERENT WASTE MATERIAL FOR PRODUCTION OF SINGLE CELL PROTEIN

### 3.3.1 Dairy waste

During last 45 years, the dairy Industry in India has grown from an unorganized sector to a vastly complex organized industry with huge magnitude during the last 45 years. India ranks first for milk production in the world. But, nearly 2% of the milk handled in a dairy goes out as waste water and the volume of wastewater generated is 2- 10 times the milk processed. The dairy effluents have a high organic content, lactose and protein these are potential biochemical sources and increases pollution problems with high BOD and COD (Kim and Lebeault, 1981; Singh et al., 2011; 2014; Spalvins et al., 2018). Therefore, dairy industry has high pollution potential and requires appropriate awareness. From cheese production alone, the global dairy industry generates around 139 million tonnes of whey every year of which about 50% are simply dumped in sewage systems or in local water bodies (Ghaly et al., 2007; Yadav et al., 2013; Yadav et al., 2014). Dairy wastes are high in lactose, therefore can be used as suitable substrate for SCP production, using microorganisms capable of fermenting lactose.

### 3.3.2 Fruits and vegetables

India, the 2$^{nd}$ largest producer of fruits in the world. Processing of fruits and vegetables produces different variety of by-products such as solid residues peel, seeds, stones, stem and pulp. Industries involved in preparation of the beverage generates around 25-60% by-product (Bhalla and Joshi, 1994; Scerra et al., 1999). Incorporation of selenium to the fruits and vegetable waste could enhance the biomass production of *S. cerevisiae*. Different substrates which have been utilized for SCP production are capsicum wastewater (Zhao et. al., 2009), potato starch wastewater (Bingnan et al., 2013), cucumber waste (Kumar et al., 2012), lemon pulp (De Gregorio et al., 2001), orange peels (Aggelopoulos et al., 2014), apple pomace (Nigam and Singh, 1996), banana peel (Unakal et al., 2012) and pineapple peel waste (Mensah and Twumasi, 2018). Solid state fermentation of the apple pomace was carried out after inoculating with *A. niger* for protein enrichment and was utilized as feed for animals (Nigam and Singh, 1996). Dhanasekaran et al. (2011) reported the efficiency of waste generated from pineapple (1–5% pineapple hydrolysate) on using *S. cerevisiae* and *Candida* for the production of SCP and no other sugar was added into the process.

### 3.3.3 Cereals and pulses

Agro-industrial wastes generated from cereals crops or their residue is also potential substrate for SCP production using different single cell micro-organisms. rice bran or de-oiled rice bran from cereals crops have been extensively used for SCP production using culture of *Aspergillus oryzae* MTCC1846 as rice bran is rich in cellulose, bran, which is almost 40 million metric tons rice bran produced every year, has been discarded as unfit for human consumption (Ravinder et al., 2003, 2006). Endophytic fungi inoculum i.e. *Cladosporium cladosporioides* have also been utilized to produce SCP with rice bran as substrate using solid state fermentation (Jaganmohan et al., 2013)

### 3.3.4 Meat and marine

By- product from meat industry is Collagen, the insoluble protein of connective tissue presents within the skins of most mammals; it is the most abundant protein in animal tissue with 30% of the total protein. Thus, a large amount of collagen is produced from animal slaughter operations. Collagen derived substrate can produce single-cell protein (Bough et al.,1972). Other by product from meat industry is poultry waste. It has high concentrations of microelements and macroelements with high composition of organic compounds with 60%-70% nitrogen content as compared to other meat industry wastes (Mitchell and Tub, 2003; Stanely et al., 2004; Kargi et al., 2005; Jalasutram et al., 2013) and is most suitable for processing of SCP. Marine yeasts (*Candida* species, *Rhodotorula* and *Leucosporidium*are), highly versatile agents of biodegradation (Kobatake et al., 1992). Use of prawn waste matter into valuable products would help in reducing the waste geeration. As per FAO, in 2015, crustacean production from aquaculture and wild capture was 13.9 MT (FAO, 2018b), from which 70-80% constitutes as processing waste (Mauldin and Szabo, 1975; Anderson et al., 1978). These are not environment friendly. In crustacean, high concentration of chitin is present. By hydrolysis of chitin as nutrient for SCP production, it is possible to obtain very high protein concentrations in microbial biomass (Rhishipal and Philip, 1998).

## 3.4 SAFETY OF SCP

SCP is getting attention by growers in recent days as for their production need limited area and also assist in utilizing of waste material from agro waste and non-agro waste (Hojaosadati et al., 2000). From the nutritional point of view, the limitation in use of SCP consumption is high quantity of nucleic acids especially RNA in bacterial species. As presence of high amount of Nucleic acid in diet leads to health issues i.e. allergic reactions and stone formation in gout or kidney (Nasseri et al.,2011). Several methods have been proposed to reduce nucleic acid levels through chemical and enzymatic treatments so, that it can be within the acceptable level. Another issue is cell wall which is non-digestible and unwanted color and flavors present in algae and yeast which must be removed before consumption because it can cause skin problems, gastrointestinal issue etc. (Adedayo et al., 2011).

## 3.5 CONCLUSIONS

As bio development increases, by-product utilization would promote the activities of food, pharmaceutical, cosmetics and petroleum sectors. Role of micro-organisms in waste utilization has been studied extensively and recorded high protein content on fermentation. Yield in protein content can be increased with optimisation of carbon sources, nitrogen sources, pH and inoculum percentage in the medium. Solid state fermentation is mostly done for the utilizing the waste as a substrate to produce biomass, because microorganisms generally grow in combined condition of lower water activity & intractable solid substrate (in which no free liquid is present), Moreover higher yield of fungi has been reported in solid state fermentation as compared to the submerged fermentation. Also cost of Single cell protein reduced by submerged fermentation is higher than solid state fermentation. So, Solid state fermentation with non-toxic and non-pathogenic species inoculum using cheap and economical substrates can be effectively used for the production of single cell protein.

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# Chapter 4

# Edible insects: Prospects for food security

**Harloveleen Kaur Sandhu, Rachna Sehrawat, Arun S. Mujumdar**

## Contents

## 4.1 INTRODUCTION

Insects has been used since old age for consumption as indicated by archeological evidence and evolution of humans as an entomophagous species has been clearly demonstrated by the analysis of fossilized feces (Sutton, 1995; Raubenheimer and Rothman, 2011). Insects are majorly used as part of cuisine in South-East Asian countries, North-Eastern India, and in portions of Australia and Europe as well. Consumption of insects as part of diet is aliened to major section of society. Practice of entomophagy in around 113 countries across the globe with about 2000 documented insect species (Jongema, 2017) has been seen by United Nations as a plausible answer to the scarcity of world food stores (van Huis et al., 2013). For some sections of society, it is considered as food for poor/backward people but by no means always a poor man supplement. As it is sold as luxury food items in several countries for example, in Thailand 150 different insect species including wasps, bamboo caterpillars, cricket, and locusts, mostly wild-harvested and are an essential staple in the diet (Yhoung-Aree, 2010), rice-field grasshopper known as inago and hornets in Japan, wichety grubs (Cossidae), bogong moth, and bardee larva in Australia, escamoles (pupae of an ant species) and grasshopper, gusanos (butterfly larvae) in Mexico, palm Weevil in Ghana and ant in China, palm weevil (*Rhynchophrus Phoenicis*) larvae in Kenya and Burkina Faso (Kelemu et al. 2016).

It is a superlative satire that billions are spent every year all over the world to save crops which contain just 14% or less of plant protein by murdering an alternative and an important source of food i.e. insects which may contain high-quality animal protein up to levels of 75%. (Premalatha et al., 2011).

## 4.2 THE SUPERIORITY OF INSECTS AS A SOURCE OF ANIMAL PROTEIN

Growing world population highlights the major issue of food security in developing countries but the food produced should ensure safety as well as the ecological stability. Insects satisfy both these requirements. Insects on one hand are nutrient rich and source of high-quality animal protein and on the other offer ecological advantages over the conventional meat being consumed all over the world (Belluco et al., 2013). Animal protein is the major source of protein consumed by people all over the world but the rearing of livestock alone generates 18 percent of the greenhouse gas emissions. With the increasing demand of meat all over the world, livestock rearing will seriously impact the global environment. Whereas on other hand insect production produces negligible GHGs. According to a UN report beef releases around 2700 GHG eq. (g/kg mass gain) which is negligible in instance of the insects for the same amount of protein produced. Eating of insects is also considered more ethical than the meat since eating meat inflicts a great deal of pain to the animals. But the study of insect nervous systems has revealed that they do not feel pain. Thus killing of insects for food will not be an ethical concern.

Insects are poikilothermic i.e. they require much less energy and nutrients for their growth as against the livestock which is considered lifeblood of all the non-vegetarian population across the world (Lindroth, 1993). Insects also produce far more animal protein than the conventional livestock for every kg of phytomass consumption since they are better efficient for its conversion into biomass (Nakagaki and DeFoliart, 1991). Thus insect rearing puts much less strain on environment than the macro livestock.

Insects also have a higher prolificacy and produces far more off springs which reach adulthood within days as against the conventional livestock which produces too few offsprings in a year and which take months to years to reach adulthood.

This makes insects and easily accessible and better source of protein than the conventional ones.

## 4.3 REASON TO IGNORE ENTOMOPHAGY

Insects have no doubt varied opportunities to be used as a food source, but there are a number of issues which make it difficult to shift to entomophagy. The possibility of the presence of anti-nutrient properties, concerns related to food storage, allergic reactions etc. (Dobermann et al., 2017). The presence of chitin, nitrogen based exoskeleton is a potential anti-nutrient factor which interferes with the protein digestibility (Belluco et al., 2013). The prospective toxicity of some compounds in insects is a cause of worry and apprehension. Toxic insects can be cryptotoxics or phanerotoxics. Cryptotoxic insects either synthesize toxic substances or accumulate them from their diet. Phanerotoxic insects on the other hand have specific organs that synthesize toxins (Belluco et al., 2013). However, the insects commonly consumed do not fall under either of the categories. Overall, there is limited data available on anti-nutrient properties of edible insects which calls for more study on this aspect. The presence of microbial load especially spore-forming bacteria and enterobacteriaceae and allergic reactions of various insects, which have been explained in detail below, are also a major concern before accepting entomophagy.

## 4.4 POTENTIAL OF INSECTS

Potential of insects as a nutrient rich source and a source of high quality protein, the use of insects providing an ecological advantage over conventional meat and the economic benefit that the production of insects provide for their production for animal feed and human food has made insects a genuine alternative food source instead of conventional meat. High reproductive capacity, ability to fly, ability to diapause and hibernate, their small size and high feed conversion efficiency make it easier for insects to grow even in harsh conditions and this feature distinguishes them from livestock rearing which cannot survive the harsh conditions. The sexual reproductive behavior of insects, facilitates the rise of new strains with adaptable genetic make-up. Thus insects evolve rapidly to the adverse conditions whereas plants and livestock require several years for the same adaptive changes.

## 4.5 NUTRITIONAL ASPECTS OF INSECTS

Rapidly increasing world population has further amplified the need for protein sources but the extent of accessible farmland is restricted. An estimated over 9 billion population of the world by 2050 will result in an added need for food of half the current needs. In this time of wide spread world hunger, shrinking area under farming, nutrient deprivation among people, deaths due to lack of proper food and decreased availability of protein rich food to feed the world, insects can be considered as an option to help eliminate world hunger. Insects are a good source of high-quality protein, lipids, carbohydrates and certain vitamins (DeFoliart, 2009). They are generally composed of protein, fiber, nitrogen-free extract (NFE) and ash (Rumpold and Schluter, 2013). Insects have substantial energy contents due to their high protein and fat content even in comparison to meat. The nutrient composition of the insects may vary dependent on the species and the developmental stage. *Cleoptera* species vary in the protein content from 8.85% to 71.10%. **Table 1** gives the nutrition composition of the common insect orders. The insects of the order *Coleoptera* are the highest consumed constituting 31% of the total insects consumed and those of the order *Lepidoptera* have the highest energy value and constitute 18% of the all insects consumed. The table clearly shows that the insects are a rich source of protein and fat.

**Table 1:** Proximate composition of insects and common animal (Rumpold and Schluter, 2013).

| Order | Insects | Protein (%) | Fat (%) | Fiber (%) | NFE (%) | Ash (%) | Energy (Kcal/100g dm) | No of insect species, consumed worldwide (%) Total no 1909 |
|---|---|---|---|---|---|---|---|---|
| Blattaria | Cockroaches | 57.30 | 29.90 | 5.31 | 4.53 | 2.94 | - | |
| Coleoptera | Beetles, grubs | 40.69 | 33.40 | 10.74 | 13.20 | 5.07 | 490.30 | 31 |
| Diptera | Flies | 49.48 | 22.75 | 13.56 | 6.01 | 10.31 | 409.78 | 2 |
| Hemiptera | True bugs, cicadas, leafhoppers, planthoppers, scale, insects | 48.33 | 30.26 | 12.40 | 6.08 | 5.03 | 478.99 | 10 |
| Hymenoptera | Ants, bees, wasps | 46.47 | 25.09 | 5.71 | 20.25 | 3.51 | 484.45 | 14 |
| Isoptera | Termites | 35.34 | 32.74 | 5.06 | 22.84 | 5.88 | - | 3 |
| Lepidoptera | butterflies, moths | 45.38 | 27.08 | 6.60 | 18.76 | 4.51 | 508.89 | 18 |
| Odonata | Dragonflies, damselflies | 55.23 | 19.83 | 11.79 | 4.63 | 8.53 | 431.33 | 3 |
| Orthoptera | Crickets, grasshoppers, locusts | 61.32 | 13.41 | 9.55 | 12.98 | 3.85 | 426.25 | 13 |

### 4.5.1 Protein contents and amino acid spectra

Insects contain high amounts of good quality proteins. Average protein content in the insect orders vary from 35.34% for Isoptrea to 61.32% for Orthoptera (grasshopper, crickets, and locusts). Within different orders species like *Brunaea alcinoe (caterpillars)(74.34%), Cirina forda Westwood (caterpillars) (74.35%), Melanoplus mexicanus (77.13%), Melanoplus femurrubrum (77.0%), Romalea sp (75.30%), Sphenarium histrio (77%), Boopedon af. Flaviventris (75.95%)* are among the species with highest protein content. Some insects contain even higher protein when compared to protein rich sources like spinach (49%), mushroom (38%), dry soya beans (35.8%), beef (25.8%), chicken (23%) and eggs (12%). Thus insects are an excellent alternative protein source especially those from the order Orthoptera. The protein quality of most of the insects is comparable to that of casein and egg protein. The quality of protein of spent silk work pupae was found to be of lower protein quality but had a higher chemical score regarding food intake, weight gain, protein digestibility, Protein Efficiency Ratio (PER) and net protein utilization (NPU). Removal of chitin from the insects using alkaline treatment helped in increasing the nutritional quality of the insect protein by improving its digestibility, amino acid availability, NPU and PER. The average amino acid spectra of the insect show the insect protein to be rich in Phenylanaline + Tyrosine, Leucine and Valine. The proteins present in insects have lower Methionine, cysteine and Tryptophan content and a higher lysine and threonine values (DeFoliart, 1992). Insects have a potential to meet the daily amino acid requirements for methionine, methionine + cysteine for adults as set by the WHO and have these amino acids in far higher quantities as compared to conventional meats. **Table 2** shows the comparison of amino acid content of the insect *T. molitor* with the conventional meat sources and it can be seen that amino acid composition is comparable with that of beef but is far higher than that of pork and chicken meat.

### 4.5.2 Lipid contents and fatty acid spectra

After protein, the second largest component of edible insects is fat. It varies from 13.41% for order Orthoptera to 33.40% for the order Coleoptera. Among the orders, species the palm weevil larvae *Rhynchophorus phoenicis* (larvae; early stage) (69.78%), *Rhynchophorus phoenicis* (larvae; late stage) (67.83%) (Omotoso and Adedire, 2007) from order Coleoptera (beetles, grubs) and caterpillar *Phasus triangularis* (77.00%) (Ramos-Elorduy et al., 1997) from order Lepidoptera (butterflies, moths) are among the species with the highest fat content. The fatty acid composition of insects for SFA vary from 29.88 % for Hymenoptera to 43.89 % for Hemiptera (true bugs), MUFA from 22.00% for Isoptera (termites) to 48.76% for Hymenoptera (bees, ants) and PUFA from 15.95% for Diptera to 39.76% for Lepidoptera (butterflies, moths).

**Table 2:** Comparison of amino acids in insects and common animal consumed as food stuffs

| Amino acid | *T. molitor* g/kg dry matter | Pupae (g/kg fresh weight) | Beef g/kg dry matter | Pork meat (g/kg fresh weight) | Chicken meat (g/kg fresh weight) |
|---|---|---|---|---|---|
| **Essential** | | | | | |
| Leucine | 52.2 | 10.4 | 42 | 17.4 | 16.4 |
| Isoleucine | 24.7 | 6.9 | 16 | 11.4 | 9.8 |
| Valine | 28.9 | 8.4 | 20 | 12.1 | 10.4 |
| Lysine | 26.8 | 10.3 | 45 | 18.0 | 17.9 |
| Phenylalanine | 17.3 | 8.2 | 24 | 8.3 | 8.2 |
| Methionine | 6.3 | 3.6 | 16 | 5.9 | 6.2 |
| Tryptophan | 3.9 | Not reported | - | - | - |
| Threonine | 20.2 | 7.5 | 25 | 9.4 | 9.5 |
| **Semi-essential** | | | | | |
| Arginine | 25.5 | 6.9 | 33 | 13.3 | 13.4 |
| Tyrosine | 36.0 | | 22 | | |
| Histidine | 15.5 | 4.2 | 20 | 8.2 | 6.9 |
| **Non-essential** | | | | | |
| Alanine | 40.4 | 9.7 | 30 | 12.5 | 11.5 |
| Cysteine | 4.2 | 0.8 | 5.9 | 2.9 | 2.5 |
| Aspartic acid | 40.0 | 15.4 | 52 | 11.3 | 19.1 |
| Glutamic acid | 55.4 | 20.3 | 90 | 32.6 | 28.5 |
| Glycine | 27.3 | 7.8 | 24 | 10.2 | 9.0 |
| Serine | 25.2 | 8.2 | 27 | 9.0 | 8.8 |
| Proline | 34.1 | 10.2 | 28 | 8.5 | 7.3 |
| Taurine (mg/kg) | 210 | Not reported | - | Not reported | Not reported |
| **Reference** | Finke, 2002, and USDA, 2012 | Longvah and others 2011 | Finke, 2002, and USDA, 2012 | Longvah and others 2011 | Longvah and others 2011 |

### 4.5.3 Vitamins and mineral content

Insects can serve as an important source of mineral content particularly, magnesium, zinc, iron, magnesium, manganese and selenium. Insects are generally low in calcium except for a few insect species which have sufficient calcium content to meet the daily requirements of daily uptake of 1300mg/day of calcium. *Musca domestica* (larvae) of order Diptera (flies) has 2010 mg/100g of calcium which is beyond the daily requirements. *Aspongubus viduatus F.* and *Acheta domesticus* (juvenile crickets) also have high calcium content. Like calcium, insects are also not considered a very good source of potassium. Except for *Usta terpsichore* (caterpillar), *Oryctes rhinoceros L.* (larvae), *Cirina forda Westwood* (larvae) and *Zonocerus variegatus* (1st instar larvae), insects are a poor source of potassium. *Usta Terpsichore*, a caterpillar species contains 3259 mg potassium/100g of insects. This is the highest among all species of insects studied. Insects are a rich source of magnesium and phosphorus and a 100g of majority of them can fulfill the daily requirement of these minerals for an adult. *Zonocerus variegatus* (adult) contains maximum phosphorus 21,800mg/100g (Ademolu et al., 2010) and maximum magnesium content of 1910mg/100g is present in *Euschistus* sp. (Christensen et al., 2006) of order Hemiptera (tree bugs). Most insects especially of order Orthoptera are high in Zinc content and can function as zinc supplementing foods. They even contain sufficient quantities of manganese and copper to supplement the diets. Thus incorporation of insects into the daily diets can decrease iron and zinc deficiency in people of developing countries (Christensen et al., 2006). Insects are generally low in sodium and can thus be used in low-sodium diets.

Along with minerals, insects also provide several vitamins. 100g of insects are a rich source of pantothenic acid, riboflavin and biotin (FAO, 1998). 100g of insects can fulfill the daily requirement of biotin in our daily diets. However, insects lack vitamin A and C in sufficient quantities in their diets and for availability of other vitamins, careful selection of insects is important.

## 4.6 RISK IN CONSUMPTION OF INSECT AS FOOD

### 4.6.1 Microbial hazards

Insects have a complex microbiota associated with them which have can be both mutualist or pathogenic. Most of the microbes associated with insects have not reportedly caused any harm to humans and have not been reported to be associated with food spoilages. Since the insects are used as a whole along with their digestive system and its contents so it is crucial to analyze their internal microbiome. *Acheta domestica* L. (house cricket) contains bacteria of genera *Bacteroides, Citrobacter, Yersinia, Fusobacterium, and Klebsiella* as its gut microbiota (Ulrich et al., 1981). However, the microbiota may change depending upon the change in diet pattern of the insects (Domingo et al., 1998). Yellow mealworm *Tenebrio molitor* L. hosts bacteria of genera *Dermabacter, Actunobacillus, Citrobacter, Propionibacterium, Exiguobcacterium, Bacillus, Serratia, Brachybacterium, and Clavibacter* (Liu et al., 2011). Human pathogenic bacteria *B. cereus* Frankland, *Klebstella pneumoniae* Schroeter and *E. coli* Migula was found to be present in some processed caterpillars species. But presence of these microbes after processing is not indicative of gut microflora but of the post processing contamination (Gashe et al., 1997). Details about hazard might be caused by insects are enlisted in **Table 3**.

Though each insect species is associated with a different group of bacteria but few genera like Bacillus, Citrobacter, Enterobacter and Bacteriodes, and are common among the insect species (Belluco et al., 2013) and out of them Enterobacter and Bacteriodes are also associated with human digestive tract. The bacteria of the genus Yersinia found in the gut of cricket and other arthropods such as fleas can be potent human pathogens (Ulrich et al., 1981). Most of the farm raised insects are not associated with the human food borne pathogens but the insects from poultry houses were found to be associated with *Micrococcus* spp., *B. subtilis* Ehrenberg, *E. coli, Citrobacter, intermedius* Sledak and *Streptococcus* spp. which are potential human pathogens. Processing of insects like boiling can eliminate live bacteria but the bacteria spores survive and can cause food spoilage or human illness (Klunder et al., 2012).

### 4.6.2 Parasitical hazards

Presence of parasite is another potential hazard associated with consumption of insects. Insects of the order Periplaneta, Blatella, Megaselia, Dryomiza, Eristalis, Hermetia, Sarcophaga, Phormia and Triatoma have been reported to be harbor protozoa and causative agents of myiasis. Insects have been found to harbor intestinal flukes of family Lecithodendriid, Plagiorchid and Gongylonematidae. Naiads, adult dragon- and damselflies were reported to be infested with *Prosthodendrium molenkampi* and *Phaneropsolus spinicirrus* which are common intestinal flukes infecting humans (Bulleco et al., 2013). *Gongylonema pulchrum* known as “gullet worm” ass it infects the upper digestive tract uses cockroaches and bettles as the intermediate host and is a potent hazard which can infect human gut (Molavi et al., 2006). Myiasis is the infection caused to human and vertebrate animals due to transmittance of dipterous larvae topeople and animals. *Hermetia illucens, Megaselia scalaris, S. peregrina, Sarcophaga* spp., *Sarcophaga crassipalpis, Phormia regina, Eristalis tenax, Parasarcophaga, and Dryomiza formosa* have been identified as agents of intestinal myiasis, which happens upon ingestion of fly eggs, when they reach the gastrointestinal tract, and pass into the feces as larvae (Sehgal et al., 2002).

### 4.6.3 Allergy hazards

Food allergies are adverse reactions which occur upon reproducibly when exposed to a given food and our governed by immune mediated responses due to the contents of the given food (Boyce et al., 2010; Schneider Chafen et al., 2010). Allergenicity risks may be either due to the ingestion of insects as a food source or the use of insect-based food ingredient in food preparations. The first risk occurs when an individual has an allergy and upon ingestion of insects’ cross-reaction between the insect and the species to which the individual has an allergy happens. Cross-reactivity between insects (class Insceta) and Crustacean shellfish (Subphylum Crustacea) can result to likelihood of shellfish-allergic individuals exhibiting reactions to alike insect proteins. A frequently reported cross-reactivity is between house dust mites [HDM, *Dermatophagoides pteronyssinus* (Trouessart)], which is an inhalant allergen and molluscan and crustacean shellfish, which are food allergens (Antonicelli et al., 1992; Carrillo et al., 1992; Mistrello et al., 1992; Witteman et al., 1994; De Maat-Bleeker et al., 1995; van Ree et al., 1996a, 1996b; Vuitton et al., 1998; Petrus et al., 1999; Ayuso et al., 2002; Fernandes et al., 2002; Rame et al., 2002). A study has also reported an allergy to snail in individuals with HDM allergy (Antonicelli et al., 1992; Banzet et al., 1992; De Maat-Bleeker et al., 1995; van Ree et al., 1996a, 1996b; Vuitton et al., 1998; Rame et al., 2002). Another study has reported possible cross-reactivity between giant freshwater prawns (*Macrobrachium rosenbergii*) and field crickets (*Gryllus bimaculatus* De Geer) (*Srinroch et al.,* 2015).

The other cause of allergenicity risk is when the insect- based ingredient upon ingestion cause sensitive reactions in the individuals resulting in food allergy. As reported by Ji et al., 2008, ingestion of the *Bombyx mori* L species of silkworm resulted in reported in around 1000 individuals. Insects are the third major contributors of food induced anaphylactic reactions after fruits and aquatic products

(Ji et al., 2009). China had 358 food-induced anaphylaxis cases reported, out of which locusts contributed 27, grasshoppers 27 and silkworm pupa 5 of them and bee pupa, cicada pupa, bee larva, and the moth species *Clanis bilineata* contributed 1 each. A study of tertiary care hospitals in Thailand showed that, of 36 cases of food-induced anaphylaxis reported over 2 years, 7 of these were due to fried insects.

A case of allergic reactions through indirect exposure has been reported in cochineal insects from the extracted colorant, carmine. Carmine, a natural dye classified by FAO has been reported to cause rhinitis and asthma reactions in people associated in production of this dye (Lizaso et al., 2000; Tarbar-Purroy et al., 2003). Allergic reactions in foods containing carmine has also been reported. Drinking the alcoholic beverage Campari, carmine-containing yoghurt and azithromycin tablets containing carmine coating have reported to cause allergic reactions (DiCello et al., 1999; Wuthrich et al., 1997).

**Table 3:** Description of different insects and relative hazard of insect (Belluco et al., 2013; Rumpold and Schluter, 2013).

| Order | Family | Genus | Species | Common name | Hazard category | Potential hazard | Country of origin |
|---|---|---|---|---|---|---|---|
| Blattaria | Blattoidae | Blatella | *Blatella germanica* | German coackroach | Parasitical | Protozoa | Southeast Asia |
| | | Periplaneta | *Periplaneta americana* | Waterbug | Parasitical | Protozoa | Mexico; wild |
| Coleoptera | Tenebrionidae | | *Tribolium castaneum* | Red flour beetle | Chemical | Benzoquinons | Indo-Australian origin |
| | | *Alphitobius* | *Alphitobius diaperinus* | Lesser mealworm, Buffalo worm | Microbial | High bacterial count | Sub-Saharan Africa |
| | | Tenebrionidae | *Tenebrio molitor (adults and larvae)* | Mealworm | Microbial | High bacterial count | USA; reared Also Mexico; reared |
| | | *Tribolium* | *Tribolium confusum* | Confused flour beetle | Chemical | Benzoquinons | Africa |
| | | *Ulmoides (Martianus o Palembus)* | *Ulmoides (Martianus o Palembus) dermesetoides* | nd | Chemical | Benzoquinons | - |
| | | *Zophobas* | *Zophobas morio* | Superworm, zophobas | Microbial | High bacterial count | USA; reared |
| Diptera | Calliphoridae | Phormia | *Phormia regina* | Black blow fly | Parasitical | Miasis | - |
| | Dryomizidae | Dryomiza | *Dryomiza formosa* | nd | Parasitical | Miasis | - |
| | Muscidae | Musca | *Musca domestica (Larvae)* | Houseflies | Microbial | High bacterial count | South Korea: reared |
| | Phoridae | Megaselia | *Megaselia scalaris* | Humpbacked/ Coffin/Scuttle fly | Parasitical | Miasis | - |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | Sarcophagidae | Sarcophaga | *Sarcophaga peregrine* | nd | Parasitical | Miasis | South Asia |
| | Stratiomyidae | Hermetia | *Hermetia illucens* | Black soldier fly | Parasitical | Miasis | America |
| | Syrphidae | Eristalis | *Eristalis tenax* | Drone fly | Parasitical | Miasis | Eurasian origin |
| Hemiptera | Reduvidae | Triatoma | nd | nd | Parasitical | Chagas disease count | - |
| Lepidoptera | Arctidae | Lophocamp a | *Lophocampa caryae* | Hickory tussock moths | Allergic | - | North America |
| | Bombycidae | Bombyx | *Bombyx mori* | Silkworm | Allergic | - | Mexico; wild |
| | Noctuidae | Agrotis | *Agrotis infusa* | Bogong moth | Chemical | Arsenic | Australia |
| | Notodontidae | Anaphe | *Anaphe venata* | nd | Chemical | Thiaminase | South Africa |
| | Pyralidae | Piraliini | *Galleria mellonella* | Honeycomb moth | Microbial | High bacterial count | Asia |
| | Saturnidae | Gomimbrasi a | *Imbrasia belina* | Mopane worm | Allergic | - | South Africa |
| | Nd | nd | nd | nd | Chemical | Cyanogenetic substances | - |
| Odonata | Nd | nd | nd | Dragonfly bonnei | Parasitical | Phaneropsolus | Mexico; wild |
| | Nd | nd | nd | Damselfly | Parasitical | Phaneropsolus | Mexico; wild |
| Orthoptera | Gryllidae | *Acheta* | *Acheta domesticus* | House cricket | Microbial | High bacterial count | USA; reared |
| | | Sphenarium | nd | Grashopper (chapulines) | Chemical | Lead | Mexico; wild |

## 4.7 LEGAL REQUIREMENTS

Past 20 years have seen increased attention towards and the development of food and feed standards in view of the increasing globalization and increased consumer concern over quality and safety of the ingested food and over the production methods. Since the consumption of insects is not wide spread and is not widely accepted, there are no national or international standards available regulating the consumption of insects. Laws and regulations exist for beekeeping and silkworm-raising which is significant for the honey and silk industries. A few existing regulations term insects as a contamination in the food and label it as an impurity and thus prescribe their maximum limits permissible in the product. However, there are no regulations or laws present which term insects as a food and thus regulate their use, so such regulations are yet to be framed.

This absence of legal standards is a major bottle-neck for the stakeholders willing to take up insect rearing on a commercial scale for food and feed purposes. Keeping in view the vast potential of insects in ensuring food security and eliminating world hunger, it is high time to develop rules and regulations which govern the use of insects both as feed and food. Specific legal provisions would ensure to control and regulate the use of insects and as well provide the required information to the consumers. From consumer point of view, legal frameworks may focus on the information to be displayed on food packaging and the risk assessment studies of effects of insects on human health.

## 4.8 MARKETING OF EDIBLE INSECTS

Marketing of insects is not wide spread and it calls for a development of value chains to promote insect consumption and sustain its utilization in feed and food. This requires an active participation of all stakeholders involved starting from the insect farmers, transporters, consumers and government agencies to the researchers and scientists involved in product development and promoting entomophagy.

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# Chapter 5

# Drying: An indispensable solution for food security

**Rachna Sehrawat and Arun Mujumdar**

## Content

## 5.1 INTRODUCTION

In earlier times, food security and policy, gain very less attention at national and international level due to readily availability and cheap price of food, although consistent attention was given at that time over the issues of hunger, poverty and malnutrition. But continuous increase in world population has created an alarming situation for the food policy maker, concerning the global food security. The world population will be 9 billion by 2050 and projected that 60% higher demand in food as compared to today situation (Breene, 2016). One in seven people today still do not have access to sufficient food, and an equal number are over-fed (Godfray et al., 2010). Competition for natural resources, land and water are other threats to food supply and distribution leading to food insecurity. Significant amount of food goes uneaten due to postharvest losses. But, looking ahead we have to ponder over the threats of hunger, population growth, malnutrition, climate change, competition for water, land, and natural resources and to provide promising solutions to eradicate or tackle these problems in upcoming times to have a functioning global food system. Problems of political instability, spike in food price, uneven distribution of food globally and unpredictable changes has to be looked upon to make the food system resilient to shocks. Drying could be the solution for the problem of post-harvest losses which will not only helps in reducing losses but will reduce the impact of the food wastage on environment.

The diversity of physical forms of grains, fruits, vegetables, meat, marine products and insects implies that a very large variety of dryers can be used for drying and preservation such products. The Handbook of Drying among a number of other references provides guidelines for selection of dryers. As always, multiple types of dryers can be used for same application. Different dryer types powered by different energy sources maybe optimal in different regions of the world for the same commodity. The selection should be made on the basis of cost-effectiveness. The dryer design should be simple and inexpensive. It is desirable to use renewable energy where possible e.g. solar, wind, biomass, biogas etc.

Detailed discussion of dryer selection is beyond the scope of this chapter. Suffice it to note that this issue is critically important and must not be neglected. Furthermore, different dryer types are needed depending on the size; farm-scale dryers are necessarily different from those deployed on large scale.

## 5.2 FOOD SECURITY AND FOOD INSECURITY

The food security is of utmost urgency and biggest challenge keeping in mind the future projection to feed a population of 9 million people by 2050. To foresee future scenarios are need of hour to allow the planning of polices at global and national level. It was assessed by FAO of the United Nation in 2010 that around 1 billion people were estimated to be undernourished and efforts were made by scientist and institution around the globe to reduce the number to half by 2015. But still the food insecurity is the biggest challenge to feed the growing population of the world (**Napoli, 2010/2011**). So, food security thereby food insecurity is a multidimensional phenomenon encompassing four dimensions i.e. availability, access, utilization and stability of food.

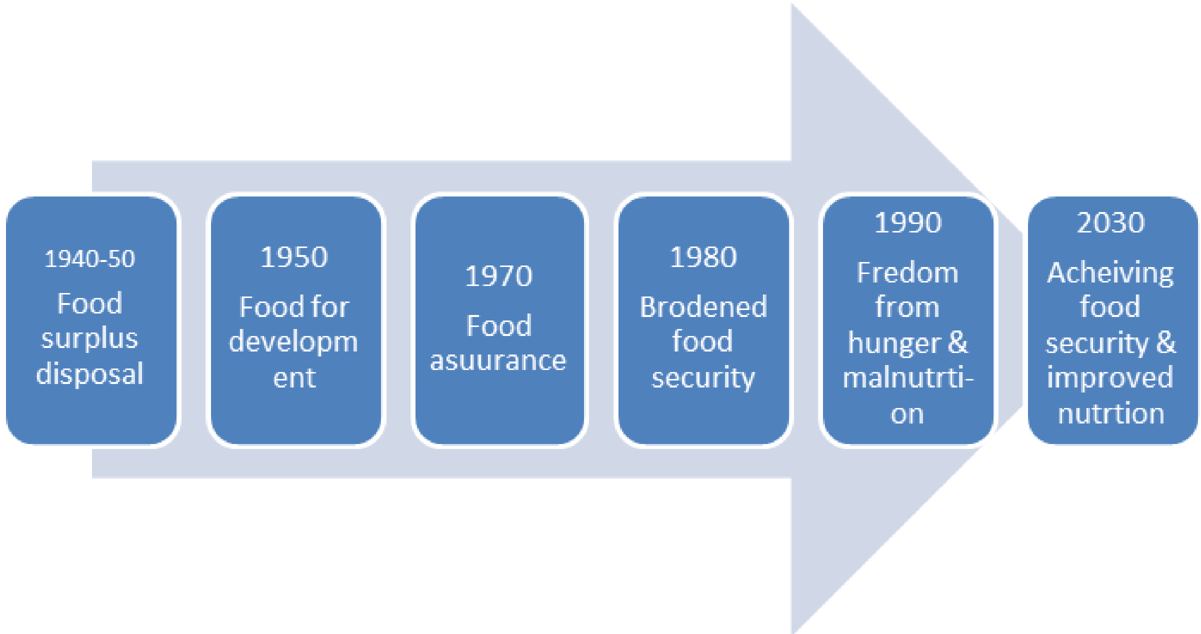


**Figure 1:** Evolution of food security concern

Concerns about food security can be traced form a conference in 1943 whose theme evolve around “secure, adequate and suitable supply of food for everyone” organized by Food and Agriculture. Later on, in 1950 bilateral agencies were formed by donor countries (USA and Canada) to supply agricultural surpluses to the countries in need. But it was realized in 1960 that food aid by donor countries might hamper a country’s progress to self-sufficiency which led to formation of World Food Programme (WFP). At that time food was available in surplus quantity. But soon the food crisis, outbreaks of famine and food prize started to fluctuate in 1970-74. On 15-16 November 1974 a conference was organized in Rome concerning the theme of “Food Security” and put an emphasis on “Every man, woman and child has the inalienable right to be free from hunger and malnutrition in order to develop fully and maintain their physical and mental faculties” and led to definition of “availability at all times of adequate world food supplies of basic foodstuffs to sustain a steady expansion of food consumption and to offset fluctuations in production and prices”. Since then the theme has evolved, developed and diversified into more than 200 definitions (Maxwell, 1996, Smith et al., 1993) depicting views and approaches to the concern of food security.

Further in 1980 the green revolution in 1980s was effective and there was increase in the food production but still the problem of feminine and poverty persisted. Then, FAO in 1983 gave a broader context that *“ …the ultimate objective of world food security should be to ensure that all people at all times have both physical and economic access to the basic food they need. Food security should have three specific aims, namely ensuring production of adequate food supplies; maximizing stability in the flow of supplies; and securing access to available supplies on the part of those who need them”*

(FAO, 1983). Further it was thought that in addition to accessibility, stability element is also required to overcome the hunger and poverty. So came up with the idea of "*Access of all people at all times to enough food for an active, healthy life*" later it was felt that another component that was important and ignored in food security concerned was quality (safe, not only energy diet but healthy balanced diet). Then in World Food Summit (WFS) in November 1996 a broad definition was given as "*Food security exists when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food which meets their dietary needs and food preferences for an active and healthy life*" which received a wider acceptance. So food security compromise accessibility, availability, utilization and stability (**Napoli, 2010/2011)**. Since food security is a broader term starting from production to consumption of food whereas food insecurity id more readily measured and analyzed and FAO definition of Food Insecurity is *"A situation that exists when people lack secure access to sufficient amounts of safe and nutritious food for normal growth and development and an active and healthy life*".

## 5.3 KEY ISSUES AND CAUSES OF FOOD INSECURITY

Reason of increase in demand of food is not only growing population but several other factors i.e. changing eating habits, shift to urban cities climate changes and water scarcity, food wastage, are major implications for food supply and food security leading to food insecurity.

### 5.3.1 Population rise, urbanization and changing tastes habits

Global population is projected to be 9 billion in 2050 despite considerable variation across countries i.e. deceleration in Europe's population, double of Africa's (from 1 to 2 billion by 2050), China will be overtaken by India around 2020 (Godfray et al., 2010). Per capita consumption also plays an important role in enhancing food demand as population goes through expansion phase (initially malnourished get access to diet like pulses, roots and tuber crop) followed by substitution phase (replacement with high energy diet food rich with meat oil and sugar) when people become more affluent resulting in nutritional transition (Popkin 1998; Godfray et al., 2010).

It means increase in demand of more meat and to produce more meat means higher requirement for growing grain implying requirement of more resources. As grains will be used to feed livestock which will then consumed as meat by human so, will be more inefficient process instead of directly consuming the grains (as bread) by humans. Consumption of diet based on meat not only increases risk of obesity but has impact on environment as well. First the animals will flatten up after consuming the much more quantity grain then it will actually produce and efficiency varies hugely. For example, in lamb it takes 4-6 kg of grain to produce 1 kg of lamb meat, and ratio of grain to meat i.e. chicken, lamb and beef is 2:1, 4-6:1 and 5-20:1 respectively. Secondly it will also belch and fart forth the notable greenhouse gases (8-18%) which damages the environment. It was also reported that to grow livestock they utilize a third of world's crop and available fresh water. As it was pointed out that 15,000 liters of water is required to feed livestock to produce 1 kg of beef but same amount of 1 kg maize or wheat it require only 1250 liters of water. Livestock meat also poses threat to lives of human due to flu or infectious diseases.

Moreover, increase in more energy concentrated food may lead to increase in obesity risk and several other associated chronic diseases. Already developing countries are managing under-nutrition problem in parts of their population has to cope with over-nutrition with changing habits and lifestyle in urban cities.

These patterns of nutritional transition are variable across different parts of world. Increase in people income in India has lower rise in high energy foods due to cultural and religious reason as compared to people with equivalent level of income in China. Availability of cheaper food with concentrated energy sugar and fat being major ingredients (generally processes food) leads to health implications and also affects overall pattern of nutritional transition. Kennedy et al. (2004) has reported lower rates of overweight and health implications due to vigorous promotion for local foods. In Sao Paulo, Mumbai and Mexico City are reported to have more than 16 million inhabitants. The reason being; availability of services and industries in urban cities, availability of wide variety of food particularly convenience food (may be less healthy). In last few decades' urbanization is increasing rapidly in developing countries for example in Asia and Africa, projected migration of 2.5 billion more resident in urban cities and certain to continue. Trend will change in upcoming future as urban population of earth is expected to exceed the population of rural areas.

### 5.3.2 Implications of climate change for agricultural productivity

Impact of climate change on global system is expected to be variable depending upon the temperature variation in different region as mentioned in **Figure 2**. Increase in temperature expected to cause increase in yield in high and mid latitude whereas lower yield at lower latitude. Additional 80 million people are expected to be at the risk of hunger by 2080, Regions of arid and sub-humid tropics would be affected more adversely for example in Africa is expected to have reduction in yield and decrease in production thereby extra people at risk of hunger (Parry et al.1999).

Extreme event (drought, feminine,), changes in mean climate, change in pests and diseases, melting of glaciers, rise in sea-level, storms give different impression of future risk on food productivity and hence security. With global prosperity the demand and competition for water between large scale industrial users, domestic users and for agriculture purpose is increasing at a faster rate. In past, groundwater reserves have been utilized at a faster rate far above their replenishment and are of particular concern for future. In upcoming future completion of different sectors will be strongly influenced by climate change which may have major effect on food production. Earlier the increase in demand of food due to rise in population was met by utilizing the available land for agriculture production. But keeping the other constraints of urbanization and rapid increase in population has decreased the option of utilization of land to meet the increase in demand of food supply (Smith et al., 2010). Expansion of new land into agriculture has been reported to be relatively modest over the last fifty years. There is little room for agriculture expansion especially in Asia and most of Europe but moderate scope can be seen in South America and sub Sharan Africa and further it might impact environment and culture due to further destruction of rainforest (Godfray et al., 2010).

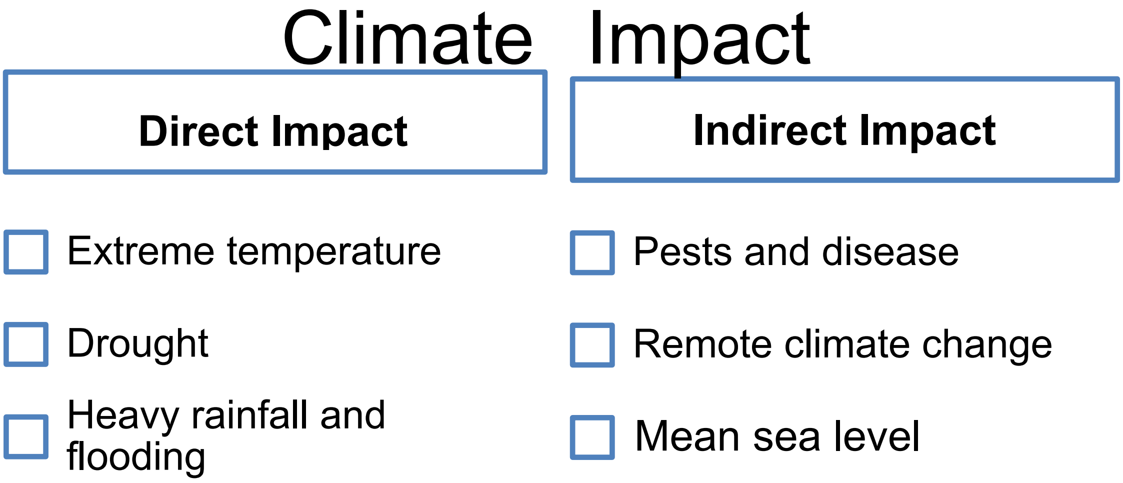


**Figure 2:** Direct and indirect impact of climate change on agricultural productivity and thereby creating food insecurity

Lobell and field (2007) studied statistical relationship between rise in temperature, precipitation and average yield for six major crops and reported annual combined losses of 40 million tonne annually, due to global warming since 1981. Although relationship of temperature with crop maize, wheat and barley was negative. Change in mean average temperature at 2020 and 2050 was compared with present scenario and it was expected that rise in temperature will be higher in high altitude region in comparison to low latitude but, even small rise in temperature in low latitudes might have more detrimental effect than high altitude on degree of warming (Easterling et al., 2007; Gornall et al., 2010). Impact of global warming on precipitation is difficult to predict but IPCC 2007 reported to have increase in precipitation in high altitude region specifically in winter and overall decrease in tropics and sub-tropics region. 80 % of agriculture is dependent on rain water, so, precipitation plays a major role in affecting agriculture productivity. Not only precipitation affects availability of water, even increasing evaporative demand due to increase in temperature could enhance the requirement of irrigation by 5-20% globally (Döll, 2002; Fisher et al., 2006) posing greater risk to food security which leads to fall in crop productivity. Extremely high temperature in Po Valley, Italy led to loss of 36% corn crop yield (Ciais et al., 2005). Up to 50% anthropogenic climate change is responsible for such rise in summer temperature in Europe (Stott et al. 2004). Drought, may be due to low precipitation, increased plant water stress, reduced stream flow and balance between demand and supply of water to society. More than 50% reduction by 2050 in major crop yield is projected due to drought (Li et al., 2009). Heavy rainfall leading to flooding implication over agriculture can even lead complete wipe of crop, soil water logging and reduced plant growth leading to lower productivity and lower quality. Lower quality refers to increase chances of fungal infection and sprouting of grain due to these extreme weather conditions. Severe cyclones or hurricanes are most likely to affect the farming in coastal areas as are at the risk of flooding and Gornall et al. (2010) reported in detail the loss of lives and crop due to tropical cyclones from 2000 to 2008. In near future chances of more intense cyclones with strong wind and precipitation under a warming climate are like to increase (Meehl et al., 2007) posing threat for food security.

Implication of climate change and elevation in atmospheric carbon di-oxide level on agricultural productivity are uncertain but can have indirect impact on crop yield. Studies have reported positive response by pests (amphids and weevil larvae) to rise in carbon di-oxide (Newman, 2004; Staley and Johnson, 2008). Rise in temperature also enable early and potential wide spread dispersion as rise in temperature reduced the overwintering mortality of aphids (Zhou et al., 1995).

Rise in sea-level due to melting of ice sheets leading to due to warming climate and due to expansion of existing mass of oceans. It is major implication for coastal areas as it poses threat to fertility of fluvial soils and small island states. Irrigated agricultural land comprises of less than 1/5 of all agricultural cropped area and accounted for producing 40-45% world's food but, these lands are generally dependent on rivers for irrigation. So dependent upon climatic conditions over these river, there flow and rainfall. For example, it is projected that by 2050 that climate change in catchment areas like the Ganges river flow is slow in dry season and although runoff comes as an increase in flow during monsoon season. So water scarcity problem may exist if water flow during peak season is not properly store and this way water availability owing to remote climate change may affect productivity and induces problem of food insecurity.

### 5.3.3 Water scarcity

Agriculture expansion is important to meet the growing demand for food due to rise in population but also increase the demand of water supply for irrigation of crop (**Figure 3**). Intensity of water scarcity is increasing. Already many of world's river basin approach closure due to water scarcity, and are only put to use for part of year (Smakhtin, 2008). In order to meet demand from other sector like industries, urbanization, and energy generation water is being pulled out from sources of agriculture used for irrigation. Vorosmarty et al. (2000) mentioned that already water resources are under stress and in upcoming future these are going to intensify further the water security. Rise in population, hunger and urbanization and change in diet are putting more pressure on available resources. Increase in per capita income causes the levels of water service to increase (municipal water usage due to individual plumbing system) and changing eating habits like more energy concentrated diets which require more water supplies in raising livestock as well as processing of meat are further worsening the situation of water scarcity.

In order to meet municipal, industrial and agricultural water supply groundwater reserve has been exhausted due to extraction especially in between 1950-2000. As the demand is going to increase the well groundwater well yield will decline rapidly and will threaten the fundamental wellbeing of citizen due to water and food scarcity (Strzepek and Boehlert 2010). Strzepek and Boehlert (2010) reported overall decrease of water availability by 18% worldwide and municipal and industrial demand is projected to be increase upwards of 200% by 2050.

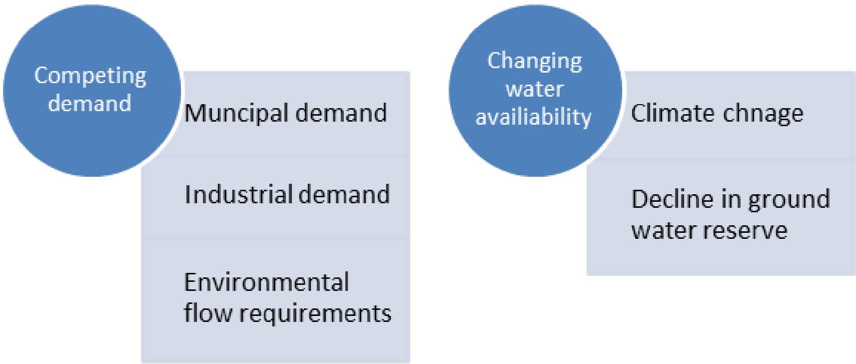


**Figure 3:** Factor affecting competition for water for food system

### 5.3.4 Food wastage

**Food loss** can be referred as decrease in dry matter or nutritive quality of food commodities which was meant for human consumption. In addition to natural disaster the reason for loss could be inefficiencies in the food supply chains which might be due to lack of proper infrastructure and poor logistics, lack of knowledge, sufficient skills, management capacity and knowledge, access to market and lack of technology. So, losses could be due to spoilage, loss in quality, loss in nutritional value, loss of seed viability and commercial losses and reason of these losses after post-harvest could be due to lack of knowledge/technology and poor infrastructure and storage facility. Term **food waste** refers to food fit for human consumption but being discarded, whether or not after it is kept beyond its expiry date or left to spoil. Spoilage of food could be due to oversupply in the markets, or might be due to individual eating habits/consumer shopping. Whereas **food wastage** includes both foods loss and food waste (Napoli, 2010/2011) (**Figure 4**).

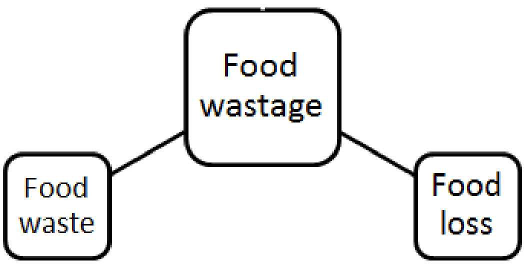


**Figure 4**

Global food wastage volumes (edible and non-edible part of food) was estimated to be 1.6 Gtonnes of “primary product equivalents” where edible part of food constitute 1.3 Gtonnes. This amount can be weighed against total agricultural production (for food and non-food uses), which is about 6 Gtonnes. An alarming wastage has been reported globally in the tune of 54% in upstream (post-harvest handling and storage) and 46% in downstream (processing, distribution and consumption) of total wastage (FAO, 2013) but it also depends on the local conditions within each country. In addition, according to the visible global pattern losses were significantly contributed by post-harvest stage in low-income regions due to financial and structural limitations in harvest techniques and with climatic conditions favorable to food spoilage but just the opposite in high income regions which contributes to food wastage in downstream phases of the food chain.

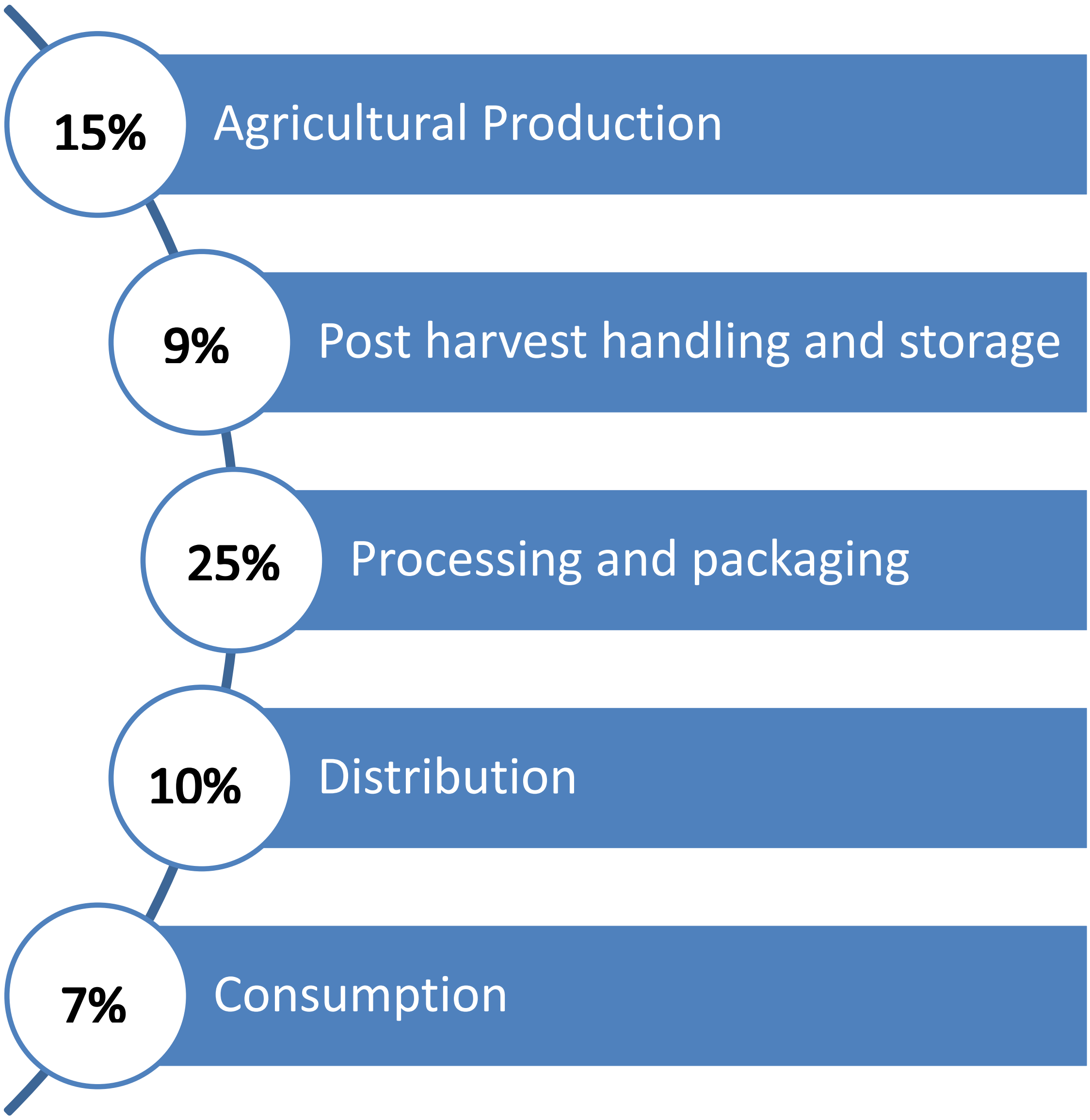


**Figure 5:** Global food losses and food waste in fruits and vegetables from production to consumption step

Thirty-one per cent of available food estimated to be of 133 billion pounds was wasted at consumer and retail level in the United States in 2010 and major losses were attributed by fruits and vegetables (44%) followed by roots crop and cereals (19%) on weight basis and were largest share was hold by cereals grains 53% on calorific content basis (Gustavsson et al., 2013; Lipinski et al., 2013). In African countries direct loss in quality and physical losses constitute 20-40% impacting huge economic losses (Fox, 2013; Abass et al., 2014). Alone sub-Saharan Africa losses grains worth amount 4 billion USD, every year as stated by World Bank report (Zorya et al., 2011). The global estimate of agricultural products (excluding seafood and fish) food wastage was worth USD 750 billion based on producer prices, which is equivalent to the GDP of Switzerland (FAO, 2013). For example, in the world India is largest producer of fruits and vegetables and generates enormous food wastage especially after post-harvest due to poor infrastructural facilities, lack of knowledge and technologies to process product and resulting in immense losses to the nation (Rais and Sheoran, 2015).

FAO in 2013 reported carbon foot print of wastage (food grown but not consumed) of about 3.3 Gtonnes of $CO_2$ equivalent emission without considering land use change. The consumption of surface and groundwater resources in the life cycle of food wasted i.e. the blue water footprint, amount to 250 $km^3$ at global scale. To grow the food wasted that was not consumed in 2007 (globally) was about 1.4 billion hectares of land, which represents approximate 30 % of the world's agricultural land area (FAO 2007; FAO 2013; Kumar and Kalita, 2017).

With such figures, prevention of these losses can contribute towards food sustainability and security which will help in combating hunger, malnutrition, improving livelihood of farmer, rural development and other such as insect infestation and rainfall. Reducing these figures will lower the need to raise food production by 60 percent to feed the estimated population of 9 billion by 20150 simultaneously reducing the undue pressure over natural resources. Otherwise these losses can have on social, economic implications, significant impact on environment and life of millions of farmers, huge world population by impacting the available food volumes and trade of commodities.

## 5.4 IMPROVING FOOD SECURITY, SAFETY AND PREVENTING LOSSES THROUGH DRY CHAIN

The above mentioned challenges, global increase in population (9.1 billion people by the year 2050), demand of food (60% higher than in 2005-2007), increasing urbanization, changing eating habits, changes in environment and completion for available water and exhausting of natural resources and food wastages due to post-harvest losses, the intensify the concerns of hunger and food insecurity. Word at international and national level has focused on improving the production and keeping check on these challenges. However post-harvest loss is a critical issue and need to be resolved and received less attention compared to other challenges. As FAO, 2013, reported we have enough food to eat but still 815 million people go hungry (FAO, 2013). It is not only unethical to let the one-third of the grown food but uneaten (about 1.3

billion ton) to go into wastage but also harm the world economically by US $1 trillion annually (Alexandratos and Bruinsma 2012; Kumar and Kalita, 2017). In order to meet the demand of rising food population and resolving the above discussed challenges making better utilization of available food with current level of production can be even resolved using different technologies like drying at different level of wastages during the supply chain. Reduction of wastage using drying will mitigate the environmental impact and will also an opportunity to improve food security globally. To combat food security a holistic approach to develop resilience food system, while sustainable use of biodiversity, available renewable and non-renewable resources. Food security is a complex condition requiring a holistic approach to all forms of malnutrition, the productivity and incomes of small-scale food producers, resilience of food production systems and the sustainable use of biodiversity and genetic resources.

Thermal drying is unit operation which involves removal of moisture content from commodities to enhance the shelf life due to vapor pressure difference. General agricultural commodities are having high moisture content ranging from 60% to more than 95%. Due to presence of high nutrients and water available for reaction they are easily susceptible for growth of micro-organism. Drying techniques helps in reducing the available water by reducing the water activity of agricultural produce.

Fresh commodities i.e. milk, fruits and vegetables, meat, marine products, are important source of protein, fat, vitamins, minerals, organic acids, dietary fiber and plays an important role in maintaining good health. However, they are prone to spoilage as cannot be kept for longer duration. It was reported that Americans consume more processed food than the fresh by a factor of 3.2 according to market statistics of 2006 (Gereffi et al., 2009; Yang et al., 2018). The benefits of dried food are convenient handling, longer shelf life, concentrated source of energy, alternative to fried snack items, and reduce bulk volume hence reduces transportation cost. Drying history is as long as human history Open sun drying has been practiced since very old age to make the food last for longer duration of time when refrigeration facilities/ electricity was not available. Although sun drying has several limitations due to contamination by environment as is carried out in open environment and dependent upon duration of sunshine and weather conditions. Harnessing solar energy using solar drying system is also gaining worldwide attention. Limitation of smaller duration time can be overcome by using phase material which prolongs drying time after sun rays become less intense. Apart from that there are several electricity based drier used to dry seeds, grains, fruits and vegetables, animal and marine products. Hot air, vacuum, freeze, spray, fluidised bed, microwave, infra-red, heat pump, refractance window, swell drying methods are used depending upon type of product, energy consumption, product quality, capacity. Several innovations like supercritical, ultrasonic assist in enhancing the drying rates reducing the drying time. The working principle advantages, limitation and innovations are reported in **Table 1**.

### 5.4.1 Drying of seeds and grains

Drying of seeds and grains is very important to maintain its viability and vigour prior to their storage. These get spoiled due to mould growth, other micro-organism activity and easily infested with insects and rodents so, moisture content should be reduced to less than 10-12% for long term storage and to and postpones germination.  Apart from sun and shade drying of seed using air can be carried out in fixed bed dryer, moving bed and in multistage mechanical dryers, and the flow of air can be Crossflow, Counter current and Concurrent (Barrozo et al., 2014). Among the upcoming technologies, since 2000, lots of work have been reported on drying of seeds/spent grains using superheated steam drying (Taechapairoj et al., 2004; Kozanoglu et al., 2006; Head et al., 2010; Bourassa et al., 2015).

### 5.4.2 Drying of fruits and vegetables

Fruits and vegetables are rich in bioactive components and generally got degraded on processing. Before selection of drying process for fruits and vegetables some attributes likes retention of color, texture, rehydration and bioactive components need to be taken into consideration. Hot air drying generally lead to poor retention of these properties but other drying technology i.e. low pressure superheated steam drying (LPSSD), refractance window drying and heat pump drying and freeze drying helps in obtaining premium quality of dried products. Fruits and vegetables can be dried in slice, cubes, shreds, or as a whole in dryers. Drying of various tropical fruits in book by Law et al. (2017) and exotic fruit in comprehensive review by Fernandes et al. (2011) has been reported in details and drying of vegetables in critical review by Zhang et al. (2017) Dried product can be utilized as snacks, ingredient in confectionary, soups preparation and with cereal flakes.

### 5.4.3 Drying of meat/marine products

Meat being rich source of essential amino acids, vitamins and minerals, characteristics flavour make it the preferred food of the consumer. High moisture content, slightly acidic pH and the presence of proteins and carbohydrate (glycogen) make it susceptible for growth of micro-organism. Moreover, people demand for convenient and nutrient rich food due to busy schedule and deficient time for cooking. Drying aids in reducing cooking time, providing healthy dried chunks as snacks and as ingredient in ready to cook food. It is also commonly used method in combination with curing and smoking to enhance the shelf-life. Drying of shrimp meat using air-oven dryer and a tunnel solar dryer was carried out by Akonor et al. (2016) found fat content higher in oven dried sample and protein, ash and rehydration behaviour was comparable as followed similar pattern using both drying method. Excessive shrinkage (80%) due to conventional drying has been reported (Ratti, 2001) but microwave drying due to volumetric heating leads to shorter drying and better quality dried meat (rehydration and lower microbial activity) has been reported using microwave method (Nayar et al., 2014).

### 5.4.4 Drying of insects

The rich nutrient composition i.e proteins, fat, vitamins, minerals and micro-nutrients of insect is attracting world-wide attention and most attractive feature is presence high amount of protein content (Belluco et al., 2013). Apart from direct consumption of insect in form of various culinary and traditional dishes in various part of world, isolated protein can be used as feed supplement and for formulation of various kind of food product. Drying of *Rhynchophorus phoenicis* was carried out using sun and electric (50 °C) method (Womeni et al., 2012) and it was reported that very long time (six days) was required to dry using sun as compared to electric method. On comparison of dried *Ruspolia differens* samples using oven and freeze retention of same nutritional quality was reported by Fombong et al. (2017) and mentioned that both of the drying can adequately utilized to develop product without noticeable nutritional changes

Apart from using dried product as convenient food, ingredients in processing of confectionary, bakery, soup preparation it also aids in reducing post-harvest loses of fresh commodities, extension of shelf-life and thereby achieving food security.

**Table 1:** **Conventional advance method of drying materials and food commodities**

| S. No | Drying Technique | Mechanism of drying | Advantages | Disadvantages | Technological revolution | Equipment parameters to be considered |
|---|---|---|---|---|---|---|
| 1 | Sun drying | Spread in thin layers or hang over wires depending upon type of product | Simple and inexpensive method<br><br>Low operating costs<br><br>Low capital costs<br><br>Material in large capacity can be dried | Long drying times Ccontamination by dust, debris, soil<br><br>Damage by pest/birds/insects/rodents is common.<br><br>Intermittent mode of drying due to non – availability of sunlight during night/rainy season.<br><br>Unhygienic due to direct exposure too environment<br><br>Chances of contamination by micro-organism due to non-uniform drying | Hybrid drying system with tray, osmotic dehydration systematic | Depends on the various parameters of temperature, humidity, wind velocity and weather conditions |
| | Solar drying | | Overcome the limitations of shade and sun drying | Less capacity<br><br>Non-availability of | Thermal energy storage allows continuous drying | Humidity, Temperature, Air velocity |

| | | | | | | |
|---|---|---|---|---|---|---|
| | | | Economically feasible and cost effective<br><br>Hygienic | sunshine thought the year<br><br>Intermittent drying enhance chances of contamination by aflatoxin | for extended hours, thereby increasing efficiency of drying and reduces total drying time. | |
| | Hot Air Drying (tray /tunnel /Cabinet) | Use of hot air as drying medium to take away the moisture present in the sample | Most common used method in industries.<br><br>Increased efficiency as compared to sun and solar drying | Quality of heat sensitive food commodities is affected as leads to destruction of bioactive compounds | Hybrid drying with advance method of drying like infrared, superheated steam, microwave | Temperature<br>Air velocity, |
| | Fluidized Bed Drying | The drying medium is passed from bottom which suspends the material kept on conveyor, in the air or fluidised state and drying medium leads to uniform drying of the particles in suspended state. | High degree of surface contact area with drying medium<br><br>High heat and mass transfer so lower drying time<br><br>Good product quality | Particles stick to conveyor but can be overcome by vibrating the fluid bed.<br><br>Restriction on particle size | Pulsed flows, Intermittent, local fluidization/spouting Combination mode of drying (spray dryer, Heat pump, freeze dryer) | Fluidisation velocity, temperature, |
| | Drum Drying | Application of slurry over outer surface of drum in form of thin layer and internal | Good porosity<br><br>Easy to operate and maintain. | High heat consumption<br><br>Adherence of sugar | Impingent drying Streams<br><br>Vacuum drum | Viscosity of slurry, drum speed, |

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|---|---|---|---|---|---|---|
| | | surface of drum is heated from inside by steam after product is dried is scraped by doctors blade and collected | High drying rate<br><br>Suitable for high solids and sugar rich slurries | rich material to the surface<br><br>Difficulty in scraping-off sugar rich commodities<br><br>Non-enzymatic browning due to heated surface might leads to cooked flavor<br>Humidification in the processing area due to evaporation | drying<br>Turbo dryer (three pass drum dryer)<br><br>Cooling mechanism to eases the scraping of adhered sugar rich foods to the surface of drum | |
| | Vacuum drying (VD) | Decrease in pressure than atmospheric causes the lowering of boiling point due to expansion of water molecules into the vapour phase | Higher drying rates<br><br>Low drying temperature<br><br>Oxygen deficient environment<br><br>Used for heat sensitive material<br><br>Good rehydration properties | Expensive as compared to hot air drying system due to additional operational and capital cost of heat pump. | Used in hybrid mode with novel and conventional drying systems to overcome problems of oxidation and reducing bioactive compounds destruction (Drum drying, super-steam, osmodehydrated, solar assisted Microwave, Infrared, rotary, Ohmic heating) | Temperature, pressure |
| | Free | Two step process | Best quality product | Highly energy | Reduction in energy | Temperature, |

| | | | | | | |
|---|---|---|---|---|---|---|
| | ze drying | involving freezing followed by sublimation<br><br>Sublimation of ice fraction present in product to vapour phase without passing through liquid phase | High porosity and rehydration properties | intensive<br><br>Very long dying drying times<br><br>Uneconomical | could be accomplished if final water activity of sample is constrained at 0.6<br>. | pressure |
| | Osmotic drying | Two step process i.e. osmosis followed by drying<br><br>Osmosis due to difference in osmotic pressure followed by drying | Low energy consumption<br><br>Used as pre-treatment | Partial dehydration process.<br><br>The rate of mass transfer is generally low.<br><br>Increase amount of added sugar/salt in the product<br><br>Leaching out of colour, acids, sugars, minerals, vitamins | Mass transfer is improved by creating partial vacuum, using ultra high hydrostatic pressure and super critical $CO_2$ treatment | Osmotic agents, ratio of sample to solution, concentration of solution, commodity size and shapes, type of material, and dehydration technique |
| | Spray drying | Atomisation of liquid/slurry into droplet form, which is further dried to a powder by drying medium | Continuous process<br><br>Easy to control parameters<br><br>Fast drying technique | Initial investment is high due to auxiliary parts like atomizer etc.<br><br>Stickiness problem | Multistage spray dryer (2-3 stages)<br><br>Ultrasonic atomizers<br><br>Superheated steam | Atomisation pressure<br><br>Feed flow rate<br><br>Feed viscosity |

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| | | | Maintains hygienic conditions during the operation<br><br>Very fine high quality powder production<br><br>Suitable for high moisture foods due to large surface area contact | on wall of dryer in sugar rich products although generally resolved by addition of high molecular weight compounds<br><br>Clogging of nozzles in high fibre products | as drying media to reduce wall deposition<br><br>Need for sugar rich foods CFD to monitor efficiency design of spray chamber | Inlet temperature<br><br>Outlet temperature |
| | Micro wave dryin g | Dipole movement of polar material i.e. water molecules under changing electric field align itself in particular direction causes them to orient and re-orient themselves (oscillate) which generates friction causing heat to generate within the material and heats the entire volume at about the same rate | Time involved in start-up and shutdown is less<br><br>Precise control is possible.<br><br>Easy to start-up and shutdown<br><br>Faster drying | Limited commercial applications<br><br>Expensive | Microwave assisted other technique like hot air, freeze drying and spouted bed drying reduces drying time and cost and increase retention of nutrients. | Microwave power |
| | Infrar ed dryin | Transfer of heat in form of radiation from the heating | High heat transfer coefficients | Fire hazards should be taken into consideration while | Combination with hot air drying, freeze drying and LPSSD | Drying air temperature |

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| | g | source upon the surface of product | Easy to control temperature<br><br>Reduces drying time<br><br>Low cost<br><br>Simple equipment<br><br>Environment friendly | design<br><br>Relatively low rehydration rates<br><br>More effective in combination mode | Use of catalytic infra- red drying technique | Infra-red power |
| | Ultra sonic dryin g | High frequency sound waves (over 16 kHz) causes rapid and alternate contractions and expansion, induces cavitation and which make water movement easy. It is useful for the removal of bound water | Improve mass transfer leads<br><br>To shorter drying time<br><br>Higher throughput<br><br>Lower energy)<br>Highly porous material<br><br>Great rehydration properties | Chances of cellular damage at high intensity waves<br><br>High installation cost | More effectively used as pre-treatment prior to osmotic and convective drying | Frequency |
| | Heat pump | Thermodynamic principle of vapor Compression cycle | Minimal energy cost<br><br>Reduced drying time<br><br>Effective in retaining the nutrients and used for heat sensitive compounds | High initial cost due to accessories i.e. heat exchangers, refrigerant filters and compressor | Hybrid drying with microwave, infra-red | Air flow rates, Drying temperature |

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| | | | Simplicity of design | | | |
| | SSD | Utilization of superheated steam (steam that has been heated beyond its boiling point) as drying medium to take moisture from the commodity | Higher energy and drying efficiencies<br><br>No oxidative or combustion reactions<br><br>Under vacuum i.e. LPSSD leads to retention of bioactive compounds better than vacuum and hot air drying<br><br>Good rehydration and porosity<br><br>No casehardening | SSD systems are quite complex<br><br>Initial condensation at start of process | Combination with infrared heaters<br><br>Impingement drying mode | Superheated steam temperature, Steam rate |
| | Swell drying | Based on abrupt transition from high pressure to vacuum leading to material expansion | Porous structure<br><br>Reduces time and energy consumption | - | Coupled with hot air drying leads to shorter drying time | Pressure and frequency of pressure drop |
| | Super critical | Moisture is removed typically using a supercritical fluid as drying medium | Low cost of materials<br><br>Drying at moderate temperatures | Materials are susceptible to undergo shrinkage after drying | Supercritical fluid assisted spray drying | Solvent, temperature and pressure |

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| | drying | under supercritical pressure (8-10 MPa) and temperature (20-50°C). Pressure and temperature cause sudden expansion of carbon dioxide resulting in moisture removal from the material | No toxic residues<br><br>Rehydration rate is fast<br><br>Good porous structure | | | |
| | Refractance window index drying | Heat from hot water is transferred to the wet food material placed in form of thin layer over conveyor belt | Low operating and capital costs<br><br>Drying time is short<br><br>Reduction reducing Micro-organisms load<br><br>High thermal efficiency | Capacity is low<br><br>Inconvenient to dry high sugar product into powder | - | Temperature of water and radiant source/film |
| | Electrohydrodynamic | Moisture removal is ensured through high voltage application between a pointed and a grounded electrode, generating ionic wind by corona discharge | Drying rate is high<br><br>Energy consumption is low<br><br>Good rehydration and overall quality of food commodity | Decreases in effectiveness as the drying process progresses | Combination with conventional mode of drying leads to an improved drying | Humidity, pressure and air flow, voltage |

## 5.5 MANAGEMENT OF FOOD WASTAGE

Dry food wastage generated from different stages of production, processing and from different sources modes i.e. municipal wastage, agricultural wastage, animals faeces can be dried to produce biomass and dried biomass further can be utilized as source of biofuels, to produce chemicals, as an animal feed, as manure/fertilizer and substrate for fermentation for production of secondary metabolites.

### 5.5.1 Dry to produce biomass as fuel source

Due to change in lifestyle, energy consumption is increasing at alarming rate which has put a stress on rapid consumption of non-renewable sources of fuels. Due to which fuel prices are rising. Dependence of human on non-renewable fossil fuels and their utilization in previous years has caused severe worries of global warming. Simultaneous we are generating huge wastage at harvesting level, during supply and chain, processing stage and at household level. It is becoming difficult to dispose of due to limitation in availability of land. But this generated biomass originating from various sources has been documented as the most promising substitute of fossil fuels. Food wastage from household, catering waste, in distribution channel and from agriculture can be converted into valuable fuels and biomass using drying.

Generally, the mass of food wastage (bagasse, fruits and vegetable, grass, and agricultural residues) constitutes high amount of moisture 5(0 to over 150%) and need to be reduced to produce low odor and inert biomass with extended shelf life without degradation (Pang and Mujumdar, 2010). These dryer reduces the bulk volume by 90% thereby making the disposal easy or further utilization or conversion in various form i.e. biofuel, manure, fermented product, animal feed and into chemicals. Also reduces the storage and transportation cost.

Drying of food wastage to produce dry biofuel, enhance energy efficiency, reduce emissions during energy conversion and improve product quality. Biofuels constitute a low-cost energy resource that is likely to continue to increase and the dryers for such products should be simple, robust, and easy to operate (Pang and Mujumdar, 2010). For drying of biomass the medium used can be air, flue gases and superheated steam. Although, a huge number dryers are prevalent in market to dry biomass but selection of dryer is very important and need in depth understanding of process. In 1970s and 1980s, rotary dryers and flash dryers uses were more prevalent (Stenström, 2017), Since 1990 use of superheated steam is more common at industrial scale due to product, energy and environment benefits associated with the technology (Pang and Mujumdar, 2010). Utilization of different types of steam dryer is based on the operating pressure type of feed material and energy consumption. Stenström (2017) reported that price for the dry biofuel of 15–20 Euro/MWh has been indicated to make a dryer installation profitable based on no cost for the thermal energy and 40 Euro/MWh as the cost for the electrical energy.

### 5.5.2 Dry to produce biomass as fertilizer/manure

The estimated yearly (2010) output of manure from world flock was reported to be 22 million tonnes (Ghaly and MacDonald, 2012). It is difficult to dump this huge wastage generated due to associated air, water and soil pollution. Apart from converting biomass into biofuel drying can be utilized to dry biomass which can be further used as source of manure due to presence of high nitrogen content. Before processing of biomass into manure/fertilizer/bio-conversion it is difficult to store the biomass due to high moisture content and odor issues. Before converting the biomass into pellets of manure it is needed to reduce the moisture content so that can help in facilitating pellets formulation, further handling and to minimize storage losses. As the food wastage generated is good source of carbon, nitrogen and several micronutrients which are important for soil nourishment and utilization of manure produced from biomass might contribute to resolve the issues of residual pesticides on surface fruits and vegetables and other food commodities.

### 5.5.3 Food waste to produce high value chemicals

Production of chemicals like ethanol from food (corn starch, sugarcane) got huge attention by industrialist as well as from the academicians, being the bioethanol generation is renewable and involves eco-friendly energy source (Ewanick and Bura, 2010; Pawar et al., 2017). But concerning the food sustainability, interest shifted to more sustainable fuel production by using non-food feedstock's like sugarcane baggase, press mud, switch grass. Benefits other than waste utilization over non-renewable sources are environment benefits (reducing green-house gas emission) and low-cost (Pawar et al., 2017).

In the process of generation of bioethanol from press mud drying was carried out at a temperature (60 to 100°C, 10-18 hrs.) using hot air oven (Pawar et al., 2017) and observed that concentration of sugar was higher at 100°C. Drying of biomass is an important step in production of biomass. The amount of moisture content to prevent microbial contamination and understanding the effect of moisture content on the bioconversion properties is also important (Ewanick and Bura, 2010).

### 5.5.4 Fermentation

Research on production of natural pigment by micro-organism using solid state fermentation is gaining wide attention. Earlier for solid state fermentation food as source of carbon, nitrogen and other minerals was commonly used such as rice, corn, but now a days trend has changed and research is being focused on utilization of waste material i.e. sweet potato peel, orange peel, corn cob (Sehrawat et al 2016, 2017a, 2017b).

### 5.5.5 Feed/meals to animals

Different byproducts generated during processing i.e. cereals wastage (broken corn, rice, cassava chip); generation of oil cakes after extraction of oil from seeds (palm kernel and soy bean meal); pulse wastage (soya bean cake after removing soy milk, broken and kernels during pulse processing) and from meat and poultry (fish cake). Further processing is important to utilize these by-products and convert into useful product for example feed to animals. During conversion into animal feed drying plays a major role and is an important step in the feed production process by restricting the biochemical reactions which promotes degradation and leads to spoilage and off odor during storage (Teixeira Freire et al., 2013). Drying also facilitates in pellet formation as well. Hot air drying of poultry waste (3 cm depth) at 60°C was most efficient to produce manure for animal feed and even effective to reduce microbial population also (Ghaly and MacDonald, 2012). Several mechanical drying operations can be used to dry the generated biomass.

## 5.6 DRYING - AN ESSENTIAL OPERATION FOR SAFE STORAGE FOODS

Around 25% of worlds agricultural produce were reported to be contaminated by mycotoxins as estimated by FAO (Kabak and Dobson 2006). Due to favorable condition of temperature and humidity especially in tropical and sub-tropical regions, during crop growth, supply chain, processing and storage the toxigenic fungi grow on food commodities and produces mycotoxins leading to economic losses (Kabak and Dobson 2006; Karlovsky et al., 2016). Mycotoxins are secondary metabolites produced by fungi which are very toxigenic, arcinogenic, mutagenic and teratogenic. Among four hundred reported toxic mycotoxins; aflatoxins, ochratoxins, zeralenone, trichothecenes and fumonisins have major health impact on human when ingested along with the contaminated food commodities as these chemical substances or metabolites can cause illness, liver and cancer incidences and death in severe cases (Jayas, 2012; Chiewchan et al., 2015). Aflatoxins and ochratoxins produced by *Aspergilus* species mainly by *A. flavus*, *A. parasiticus* and rarely by *A. nomius* are of major concern (Kabak and Dobson, 2015). Worldwide around 550,000-600,000 new liver cancer cases has been reported annually which might be due to uncontrolled exposure to aflatoxin (Liu and Wu, 2010 and Chiewchan et al., 2015). Infection and aflatoxin production by fungi in crop can occur during crop growth due to by birds, mammals, insects, and due to favorable conditions caused by moist environments in field or during transportation and storage (Achaglinkamea et al., 2017). Aflatoxin being heat stable are not easily eliminated by cooking at home, rapid drying to reduce to optimum moisture content could be one of the potential solution to eliminate the favorable growth of fungi on the food and feed and thereby achieving food security (Chiewchan et al., 2015).

Cereals, grains, and related products, nuts, herbs and spices maize, groundnuts, tree nuts, milk and meat products are more commonly found contaminated with aflatoxins (Iqbal et al., 2015). Limit of 4-30 ppb is permitted in food depending upon regulations in different countries (Hosseini and Bagheri, 2012). Permitted limit of aflatoxin in almonds, Brazil nuts, hazel nuts, peanuts and pistachios is 15 µg/kg and 20 µg/kg in Canada and USA respectively (USFDA, 2013; Minister of Justice Canada, 2014). According Codex and European Union regulations permitted levels of aflatoxin for Almonds, Brazil nuts, hazel nuts, peanuts, pistachios which are intended for further processing is 20 µg/kg. According to codex and European Union regulations for ready to eat Almonds, Brazil nuts, hazel nuts, peanuts, pistachios permitted levels of aflatoxin for are 10 µg/kg and 4 µg/kg respectively (European Commission, 2010; Codex, 2015).

Food commodities are rich in nutrients i.e. protein, carbohydrates and sugars, alcohols and acids which has shown to provide the shielding effect to micro-organism while pure cultures drying process. However, fruits exhibit low pH as compared to vegetables which is not favorable for growth of micro-organisms due to inherent acidic characteristics. Therefore, different food commodities exhibit different variations in the survival of micro-organisms due to complex composition and structure. Drying of food commodities may affect the cellular compound i.e. can induce breakdown of DNA and RNA, alteration in cytoplasmic membrane, damage to cell wall and denaturation of protein. Different technologies create stress on the micro-organism not only due to water removal but also due to exposure to variable temperature, pressure, electromagnetic waves depending upon principle of different drying processes.

## 5.7 ROLE OF ENERGY IN REDUCING THE OPERATION COST AND RECENT ADVANCES IN UTILIZATION OF COMBINATION DRYING MODE

Drying in combination mode is found to be more effective in reducing energy consumption, increases the through-put thereby reducing cost as well as better product quality (Raghavan et al. 2005; Duan et al., 2007). It is useful in harnessing benefit of multiple drying technologies and minimizing the limitation of single drying technologies for ex. air drying results in poor product quality and freeze drying provides best product quality but takes long drying time. Duan et al. (2007) reported that vacuum microwave was combined with freeze drying to lower drying time and to get acceptable product quality of sea cucumber. Better product nutritional and sensory quality of shredded squid was achieved in Infrared-Assisted Convective drying method as compared to individual methods (Wang et al., 2014) and similar results were reported by Kumar et al. (2005) while drying of onion using infra-red and hot air drying in combination mode. Borompichaichartkul et al. (2009) carried out hybrid drying using heat pump drying followed by conventional drying (hot air drying) to dry macadamia nut and found that heat pump drying (11.1% d.b.) followed by hot air drying (1-2% d.b.) results in reduced drying time.

Intermittent drying (Chua et al. 2003; Thomkapanich et al., 2007) and electrohydrodynamic drying technologies (Bai and Sun, 2011; Kudra and Martynenko, 2015) are also effective in reducing the energy consumption. Intermittent LPSSD and VD of banana chips were carried out by Thomkapanich et al. (2007) and was compared with continuous mode of drying. It was found that LPSSD at 90 °C (on:off period of 10:20 min) reduced energy consumption by 65% as compared to continuous mode of drying.

Energy saving of the vacuum pump up to 53% was achieved in case of VD and 51% in LPSSD in intermittency mode. Effect of intermittency in all the treatment (except at 90 °C with on:off period of 10:20 min using LPSSD) on quality parameters does not have significant difference. Drying of shrimp using electrohydrodynamic and oven method was done by Bai and Sun (2011) and found better product properties i.e. lower shrinkage, higher rehydration and better color, softer body and low distortion in case of samples dried using electrohydrodynamic method as compared to oven. It was concluded by Kudra and Martynenko, 2015 that energy consumption is discernibly lower in electrohydrodynamic drying method as compared to convective methods of drying. Utilization of mathematical modelling for optimisation of process is another way to reduce energy consumption (Achariyaviriya et al. 2002; Mujumdar and Zhonghua, 2008). For selection of dryer for different types of food commodities can be referred in Handbook of industrial drying (Mujumdar, 2006)

## 5.8 CONCLUDING REMARKS

To achieve food security modification of diet e.g. move from meat to vegetables, mock meats, insects to provide proteins, minimize water food print, minimize energy food print in all stages from production to preservation to processing. Global cooperation required. Utilization of drying technology is a sustainable solution in mitigation of food security. Thermal drying plays an important role in almost all aspects of interest in securing global food security ranging from production of Agri- products, transportation from areas where Food is produced to where it is consumed, safe storage to avoid spoilage due to microbes and pests, reduction of wastage of food, production of biomass to fuel dryers and production of high quality nutritional food products. It is not enough to supply enough food but also to enhance health of the consumers. This can include drying of herbs as well. Wide assortments of dryers are available to dry diverse types of grains, foods, meats, marine products etc. To obtain product with optimum cost, reduced drying time and quality, different drying techniques can be used in combination mode. Use of renewable energy is desirable to lower cost of drying. R&D in aforementioned areas will help ensure food security for the globe.

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# Chapter 6

# Ensuring food security with safety: Prevention of microbiological contamination in stored and packed foods

**S. Deepika, S. Kar, P. P. Sutar**

## Content

## 6.1 INTRODUCTION

Food security prevails when all people at all times have social, economic and physical access to safe, nutritious and sufficient food that meets their dietary requirements and food preferences for a healthy and active life (Barrett, 2010). Likewise, household-level food security implies the ability of the household to secure food either through purchase or from their own production which meets their adequate daily dietary needs for all the members of the household (Pinstrup-Andersen, 2009). Food security remains the top priority for human development, capability paradigm and global concern (Hanjra & Qureshi, 2010). Millions of people do not enjoy the acceptable range of food security. Global food insecurity persists in-spite of the progress in guiding the global vulnerable and poor regarding the basic nutritional needs.

Food insecurity is the condition in which constant access to sufficient food is restricted due to the lack of money and other resources (Nord, 2008). It is also considered as the predominant inadequate uptake of key nutrients (Adams, Grummer-Strawn, & Chavez, 2003). The major causes of food insecurity are poverty and human population growth. Other factors that are intensifying the food demand are climate change, increasing urbanization and use of land for non-consumable crop production (D. Kumar & Kalita, 2017). Even though food insecurity prevails in developed countries, it is overwhelmingly intense in developing and underdeveloped countries. Population rise, especially in developing countries, leads to the issues of food insecurity and hunger. For the increasing population, the major global concern remains in satisfying food demand, where around one-third of the food harvested has been lost during post-harvest operations (Parfitt, Barthel, & Macnaughton, 2010). For obtaining a sustainable solution to increase the availability of food, reducing the post-harvest loss in developing countries can improve farmer's livelihood, reduce the pressure on natural resources and eliminate hunger (Pretty, Morison, & Hine, 2003). Postharvest loss is a critical issue. It has been reported that the post-harvest losses can vary from 1 to 2% in well-managed storage facilities with proper drying and aeration capabilities, while the losses can extend beyond 20 to 50% in poorly managed storage structures (Jayas, 2012). In developing countries, cereal grains are the major staple food that accounts for the highest post-harvest loss on a calorific basis compared with other agricultural products. However, post-harvest loss is not acquiring the proper attention, and moreover, only 5% research funding has been allocated in the recent years (Kitinoja, Saran, Roy, & Kader, 2011; Pantenius, 1988). Due to the lack of technical knowledge, the loss of cereal grains tends to be 50 – 60%. The proper implementation of advanced storage methods can reduce the grains loss to 1 - 2% (Kumar & Kalita, 2017).

Reducing food loss and waste holds a great perspective for enhancing food security, promoting environmental sustainability and conserving resources (Shafiee-Jood & Cai, 2016). Throughout the supply chain, food loss and waste should be taken into account for maintaining the food security (Novaes, Felix, & de França Souza, 2013). Along with the national poverty reduction strategies, if the food security objectives are incorporated, then it can have an impact at the individual, household, sub-national and national levels and have a specific emphasis on reducing extreme hunger and poverty (Stamoulis & Zezza, 2003).

## 6.2 STATUS OF GLOBAL FOOD SECURITY

Over the past decade, the intensity of food insecurity has increased around the world. Especially the situation has worsened in South Western and Eastern Asia, parts of sub-Saharan Africa, which led to the negative impact on food availability and productivity. Global food production is enough to feed the world's population, while nevertheless 821 million people remain hungry according to the report of "*The State of Food Security and Nutrition in the World 2018*". World hunger has intensified, the number of estimated undernourished people increased from 777 million in 2015 to 815 million in 2016 (FAO & UNICEF, 2018).

Moreover, there will be tedious challenges for feeding more than 9 billion people by 2050 (Beddington, 2010; Evans, 2009). The food demand will be 60% higher than the current situation. Deputy Director General of FAO suggested that "in-order to meet growing food demand, agricultural production needs to increase by 100% in developing countries and by almost 70% worldwide" (Smyth, Phillips, & Kerr, 2015; Tutwiler, 2011). The United Nations aims to achieve food security, improved nutrition, promoting sustainable agriculture and ending hunger, and these objectives have been set at the second position of its seventeen Sustainable Development Goals for the year 2030. During 2016, it was estimated that 1 in 9 people suffers chronic hunger and malnutrition in the year 2014, and the undernourished people in developing countries was estimated to be 12.9% of the population (Von Grebmer et al., 2016). As of 2017 March, FAO has identified 37 countries, out of which 28 from Africa are facing food insecurity (Bank, 2018).

## 6.3 FOOD SAFETY ON FOOD SECURITY

Food security and food safety are inter-related concepts with an insightful impact on human life (Hanning, O'Bryan, Crandall, & Ricke, 2012). Food safety plays a vital role in food security status. Consistent progress in food safety potentially demolishes food insecurity. Food safety management empathizes on a variety of practices for preventing foodborne diseases. Many organizations work collectively to achieve food security using food safety. Food safety and security management provide in-depth knowledge on the problems prevailing and the solutions to complex problems with the provisioning of secure and safe food with finite resources (Tirado, Clarke, Jaykus, McQuatters-Gollop, & Frank, 2010). Even though the importance of security and safety cannot be understated, very few researchers are working on to implement the practices of food safety to ensure food security. Low yield of crops is the major cited problem for food insecurity with additional loss of 20 to 30% of the harvested crops (Tefera, 2012). Researchers have analyzed and found that one of the major reasons for the prevailing food insecurity is the improper management in the food supply chain especially during the post-harvest stages until it reaches the retailers. There are major losses during the storage stage and due to the improper knowledge of food packaging. Generally, about 30% fruits and vegetables are rendered unfit for consumption due to spoilage after harvesting. India annually produces fruits and vegetables of the value of approximately Rs. 7000 crores and in that wastage is about Rs. 2100 crores. This is a huge loss of valuable food where even the minimum food requirement of the population is not met. Therefore, it is important not only to grow more, but also to save what is grown at high cost (Rawat, 2015). Use of improved technology and storage structures can reduce post-harvest losses and increase the farmers' economic revenue.

## 6.4 ROLE OF STORAGE IN FOOD SECURITY

Storage is a part of the food supply chain, serves as a channel when the agricultural product passes from farm to fork. Storage and transportation of agricultural produce, if carried out effectively, will be a vital contribution to the solution of world hunger (Hall, 1970). While considerable quantities of the products are being lost or damaged during storage due to pests, micro-organisms and other factors. Harvested grains are mostly stored in the traditional storage structures that are inefficient to avoid the mold growth and insect infestation during storage which leads to a high level of losses. Storage losses constitute for the major fraction of all postharvest losses, and they negatively affect the livelihoods of farmers. The poor post-harvest system may lead to a rapid loss in the quality and quantity of agricultural products. Storage losses can be categorized into a direct loss and indirect loss where the former is due to physical loss and the latter is due to nutritional and quality loss (Tefera, 2012). Storage losses are also dependent on the pre-storage conditions like harvesting, threshing and drying.

Similarly, post-storage losses can be affected by conditions during storage. The factors affecting storage losses are mainly categorized as biotic and abiotic factors. The biotic factors are insects, rodents, fungi, pests, and the abiotic factors are temperature, rain and humidity. Temperature and moisture content are the most critical factors influencing the storage life of agricultural products. The rapid growth of molds occurs at 20 to 40 °C and relative humidity higher than 70% (Verdier, Coutand, Bertron, & Roques, 2014). The moisture content of the product at the lower range can maintain the relative humidity below 70%, and it limits the mold growth. Storage of high oil content product demands proper attention because at high moisture content the vegetable oil degrades and produces high fatty acid, some times it even results in self-heating of the product. Lipid oxidation leads to product deterioration, alters the aroma and taste, causes detrimental effect on human (R. Kumar, Mishra, Dubey, & Tripathi, 2007). Sometimes, the loss can also happen through spillage from leaky bags. Apart from these losses, the pests in the storage conditions cause poisoning due to aflatoxin contamination. The storage losses of agricultural products due to microorganisms, pests and the problems in traditional storage methods are discussed in detail in following sections.

### 6.4.1 Storage losses by micro-organisms

Deprived post-harvest management leads to a detrimental effect in nutritional quality of cereals, pulses, fruits and vegetables. Depending on the favorable climatic condition, the products carry the microbes during storage. Even during safe and dry storage, the microbes can be viable and keep respiring during the storage period. Microorganisms present in food can cause unacceptable changes like color degradation, losses in dry-matter due to carbohydrate utilization of microbes for energy, degradation of proteins and lipids, off-flavour generation due to the production of volatile metabolites, loss of baking quality and germination (Magan & Aldred, 2007). When food stuffs are kept unprotected, bacteria and fungi rapidly colonize and produce toxic and distasteful chemicals, which are hazardous for human health (Hammond et al., 2015). Few fungi spores cause respiratory diseases (Lacey & Crook, 1988). Filamentary fungi can produce carcinogenic micro-organisms (Marin, Magan, Ramos, & Sanchis, 2004). Depending on the product and its intrinsic factors, the microbial attack varies. Cereals are generally stored in a dry condition, so bacterial spoilage can be hindered. While for intermediate moisture products, pest and fungal spoilage are of major concern. A major portion of the grains and pulses have been reported to be rejected because of the presence of mold and infected grain leading to a drop in quality (Nagy, Korzenszky, & Sembery, 2016; Senthilkumar, Jayas, White, Fields, & Gräfenhan, 2016).

**Table 1** gives the list of harmful microorganism and their impact on human health. In food grains, mycotoxin contamination makes the food unsuitable for human or animal consumption. Approximately 25 to 40% of the cereals are affected only by mycotoxins worldwide (R. Kumar et al., 2007). Even spices have high potential to be affected by toxigenic fungi and mycotoxins, especially aflatoxins and ochratoxin A (Kabak & Dobson, 2017). Fumonisins, aflatoxins, ochratoxins, and deoxynivalenol are the most important and common mycotoxins (Kimanya, De Meulenaer, Van Camp, Baert, & Kolsteren, 2012). The major mycotoxigenic mold *Penicillium verrucosum* (ochratoxin) is commonly found in damp climates like Northern Europe. Similarly, *Aspergillus flavus* is commonly observed in tropical and temperate conditions (Magan & Aldred, 2007).

The presence of aflatoxins in food materials is comparatively high in warm and humid climate, especially in tropical and sub-tropical regions, that provides optimum condition for the growth of molds (Chiewchan, Mujumdar, & Devahastin, 2015). Molds and mycotoxins cause quality and dry matter loss, and are hazardous in the food chain (Magan & Aldred, 2007). Fungi species *Aspergillus parasiticus* and *A. flavus* produce aflatoxins as a secondary metabolite, that are the most dangerous mycotoxins which affect growth in children and increases the risk of liver cancer (Laursen, 2014; Turner et al., 2005). Due to food contamination by aflatoxin, approximately 4.5 billion people are exposed in developing countries (R. Kumar et al., 2007; Williams et al., 2004). Aflatoxicosis, caused by the higher concentration of aflatoxin can lead to severe illness and even death (Tefera et al., 2011). Aflatoxin contamination can occur during two phases, crop growth and from crop maturation till consumption. Molds existence during storage reduces germination and damages the grain. Additionally, it damages the quality of the grain due to increased fatty acid, reduced sugar, starch content and the development of off flavor. Major reason for microbial attack in stored agricultural materials is due to the presence of moisture content above the safe limit. **Table 2** gives the major storage fungi at different moisture content. In developing countries at farm level storage, even vertebral pests can damage a large portion of the agricultural produce, while the presence of fungi can be the main reason for deterioration at higher relative humidity storage. Proper handling of produce and using scientific storage methods one can reduce losses of less than 1% (Costa, 2014; Qiu & Jin, 2003).

**Table 1:** Microorganism, associated food and their impact on health

| Microorganism | Associated Foods | Health issues (symptoms) |
|---|---|---|
| *Clostridium perfringens* | Poultry, , fish, , stews, raw meat beef, gravy dressings, spices and vegetables | Watery diarrhea Intense abdominal cramps food poisoning caused by *Clostridium perfringens* |
| *Staphylococcus aureus* | The red meats like poultry, tuna salads, potato, ham, macaroni, custard, sandwich sauces and bakery product. | Food poisoning (Abdominal cramps, fever, diarrhea, vomiting and nausea) |
| *Clostridium botulinum* | Vegetables, improperly processed canned meats, beef, and fish, honey, spinach asparagus, mushroom and peppers | Botulism ( Diarrhea, vomiting, blurred and double vision, difficulty in swallowing, muscle weakness, respiratory failure and death) |
| Listeria monocytogenes | meat products (sausages and pate), dairy (coleslaw and soft cheeses), ice-cream, butter, raw and fermented meat, fishes, poultry, cold-smoked trout products | Listeriosis (Diarrhea, Fever, muscle aches, and nausea, Pregnant women may have mild flu-like illness, and infection can lead to premature delivery or stillbirth. The elderly or immune-compromised patients may develop bacteremia or meningitis.) |

| | | |
|---|---|---|
| Escherichia coli OI57:H7 | Ground beef, raw milk, chicken, fruits, vegetables, and fecal matter exposed food, contaminated food | Hemorrhagic colitis, Severe (often bloody) diarrhea, abdominal pain along with vomiting and mild fever leads to kidney failure.) |
| *Yersinia enterocolitis* | Milk and meat products, raw vegetables, raw pork, fofu, contaminated and cross contaminated food | (Lymph node Inflammation, Appendicitis-like symptom) |
| Campylobacter species (C.coli, C fefunii susp fefunii, C. lari, and C. upsaliensis and C. fetus subsp. fetus). | Raw meats (pork and beef) water, unpasteurized milk, eggs, chicken, mushroom and shellfish. | Campylobacteriosis (Diarrhea, cramps, fever, and vomiting; diarrhea may be bloody) |
| Bacillus cereus | Cereals, vegetable and meat dishes, custards, spices, deserts and puddings | Abdominal cramps, Nausea,<br>Watery diarrhea, and Vomiting |
| Salmonella | Milk and milk products, poultry, meat, fish, shell fish, yeast, shrimp, salad dressing, sauces,<br>Raw meats, poultry, frog legs,<br>toppings, peanuts and peanuts butter, cake mixes, dried gelatin, creamy desserts, chocolate, pork and cocoa<br>Commonly salmonella contamination is more in pork and poultry than beef. | Severe abdominal cramps, acute gastroenteritis, vomiting, fever (100°F to 102°F), diarrhea, sometimes bloody diarrhea, body ache, head ache,<br>vomiting, headache and body aches |
| Toxoplasma gondii | Pork, raw or improperly cooked meat and water | Swollen lymph nodes, fever, muscle ache, head ache,<br>Fever, swollen lymph nodes, seizures, psychosis, confusion, |

| | | |
|---|---|---|
| | | miscarriage in pregnant women, |
| Shigella | Potato salads, vegetables, chicken, poultry, seafood , dairy and meat products, | Bacillary dysentery or shigellosis (Fever, diarrhea, abdominal cramps, blood and mucous in stool) |
| Entamoeba hystolitica | Ice cream, tap water, ice cubes, shellfish, salads, eggs, pealed fruits, sauces, raw and improperly cooked meats | Amoebiasis; High dysentery, stomach pain, rectal pain, amoebic dysentery, excessive gas, sometimes infect liver, weight loss |
| Vibrio vulnificus | Raw and improperly cooked seafood (shell fish and oysters) | Fever, abdominal pain, diarrhea, vomiting, internal bleeding in ulcer and skin, More deadly to weak immune system and liver diseased person |
| Hepatitis A | Raw and uncooked foods, contaminated shell fish | Hepatitis (Jaundice, headache, fever, abdominal pain, nausea, dark urine and diarrhea) |
| Noroviruses | Raw and uncooked foods, Contaminated food and drinking water and contaminated shellfish | Food infection and poisoning viral and non- bacterial gastroenteritis, (Diarrhea, vomiting, fever, headache and abdominal cramp) |
| Cryptosporidium | Contaminated food and drinking water due to ill handling | Intestinal cryptosporidiosis (Stomach cramps, slight fever, watery diarrhea and stomach, slight upset) |
| Cyclospora cayetanensis | Different fresh produces (lettuce, imported berries, basil) | |

### 6.4.2 Storage losses by pests

Production of crops grown for consumption is at high risk due to the prevalence of weeds, pathogens, and pests, especially animal pests. Cereal grains are a major source of carbohydrates that makes it highly susceptible to vertebrate pests' attack. Vertebrates like birds, insects and rodents often remove grains from warehouses, so losses caused are frequently found by the difference in quantity. To prevent pest attack, warehouse with proper sanitation can maintain minimal dry matter loss.

Additionally, integrated insect control, screening to eliminate pest and maintaining dry storage condition can minimize the storage losses (Dubey, Srivastava, & Kumar, 2008). The insects in storage can cause both damage and losses to the product. "Damage" is the physical evidence of deterioration like holes in the grains. "Loss" is the quantitative measure like the total disappearance of the product (Boxall, 2002).

**Table 2:** Major storage fungi at different moisture content

| Major storage fungi | Commodity | Moisture (%) |
|---|---|---|
| *Aspergillus flavus* | Soybeans | 17.0-17.5 |
| | Starchy cereals | 17.0-18.0 |
| *A. ochraceus* | Sunflower | 9.0-9.5 |
| | Soybeans | 14.5-15.0 |
| | Starchy cereals | 15.5-16.0 |
| *A. candidus* | Sunflower | 9.0-9.5 |
| | Soybeans | 14.5-15.0 |
| | Starchy cereals | 15.5-16.0 |
| *Eurotium glaucus* (blue eye) | Sunflower, Safflower, | 9.0-9.5 |
| | Peanuts Soybeans | 12.5-13.0 |
| | Starchy cereals | 14.5-15.0 |
| *Pencillium* (blue eye in corn) | Sunflower | 10.0-15.0 |
| | Soybeans | 17.0-20.0 |
| | Starch grains | 16.5-20.0 |

Source: (Mohapatra et al., 2017)

### 6.4.3 Storage losses in traditional structures

In traditional storage systems, due to the climatic changes, temperature fluctuation causes moisture accumulation either on the top or bottom of the produce. Proper care should be taken by maintaining the temperature gradient inside and outside of the infrastructure (Abedin, Rahman, Mia, & Rahman, 2012). The storage structures depend on the countries, in South Asia and Africa; grains have been stored as bulk in simple granaries constructed by bamboo, bricks, straw and mud. Pots and mud bins, Kothis, plastic containers and Bokhari (straw structures) are the commonly used storage systems in Asia. Polythene and gunny bags are used for short-term storage, while Berh, Dole, Motka, Gola, Plastic/Steel drums are used for long-term storage (Hell, Ognakossan, & Lamboni, 2014). In African countries, Kedelin and Ebli-va are the in-house smoked storage in Togo (Pantenius, 1988). Polypropylene or jute bags, conical structures, baskets and raised platforms are the common storage materials/structures in West Africa (Abass et al., 2014). Farmers in Southern and Eastern Africa use cow dung ash in wood cribs, small bags, pits, metal bins and iron drums enclosed with muds

(Wambugu, Mathenge, Auma, & Van Rheenen, 2009). In Kenya and Malawi, “Nkokwe” is the commonly used storage structure, it is a cylindrical basket made of intertwined split bamboo and enclosed with a conical roof of grass (Schulten, 1982). Most of these traditional structures are not made of scientific analysis and hence causes damage and loss to the products by various factors like pests, microorganisms and leakage.

### 6.4.4 Prevention methods for storage loss

Storage losses and damages can be reduced by avoiding the entry of rodents and insects. Additionally, it can be minimized by avoiding the growth of micro-organisms by maintaining the appropriate environmental conditions. Proper knowledge on processing steps before storage (harvesting, drying) and its control points can reduce the losses during storage. Timely preventive steps taken for biotic and abiotic factors can control the storage losses. One of the solutions to this dilemma is increased efficiency and waste reduction in the food supply chain. By improving the understanding of stored-grain ecosystems, using novel technologies for preservation and by adopting loss detection, it is possible to increase grains available for consumption (Jayas, 2012). Furthermore, pretreatment and suitable controlled drying can be used as efficacious tools to control the presence of aflatoxins during processing (Chiewchan et al., 2015). Dried herbs, fruits and vegetables have been consumed and traded increasingly, as an ingredient or whole throughout the world. Several outbreaks and microbial hazards associated with dried products have been reported world-wide (Hiramatsu, Matsumoto, Sakae, & Miyazaki, 2005; Paton et al., 1996). Research works should be conducted on a wide range of micro-organisms, and extrapolating results from the pasteurisation should be avoided.

Drying can increase the heat resistance of micro-organisms. The effect of drying process on micro-organisms should be analysed in a systematic way and then comparing with pasteurisation can provide the antagonistic or synergistic effect of stressful conditions and water activity on micro-organisms. Overall, the evidence is still scarce and more research is required to understand the effect of drying on micro-organisms, as an input for maintaining food security (Bourdoux, Li, Rajkovic, Devlieghere, & Uyttendaele, 2016). Studies on microwave and infrared radiation assisted microbial destruction have been attracted by the quick and effective heating of the food. Some researchers reported positive results on microbial inactivation of spices by microwave and infrared radiations. Microwave inactivates yeast and mould, *Aspergillus niger* fungus and many harmful microorganisms like *Bacillus spp*., and *B. licheniformis* (Behera, Sutar, & Aditya, 2017; Kar, Mujumdar, & Sutar, 2018; Kim et al., 2009; Wang, Hu, & Lin, 2003). The continued growth in the application of microwave and infrared radiation assisted sterilization of spices provides strong evidence in favour of viability of the technique. High power microwave assisted process helps in quality preservation and improves shelf life (Shirkole & Sutar, 2018a). Research study revealed that decreasing storage temperature and use of low permeable packaging material can control quality degradation (Shirkole & Sutar, 2018b). Hybrid drying can be helpful in preventing postharvest losses by lowering the water activity of the product

(Deepika & Sutar, 2017). Infrared and microwave hot air drying saves energy and drying time and maintains quality of the dried product (Deepika & Sutar, 2018). Furthermore, implementation of cutting edge technologies can tackle the global food insecurity. Biocontrol technologies, in aggregation with other aflatoxin control tools like storage, sorting technologies, ozone fumigation, irradiation, biological and chemical control along with packaging have the possibility to enhance international trade, link farmers to markets, improve the health condition of humans and animal and that can thereby increase the food safety and security (Udomkun et al., 2017).

Packaging has a vital role to play in containing and protecting food as it moves through the supply chain to the consumer (Verghese, Lewis, Lockrey, & Williams, 2013). Although it is a huge challenge, storage losses can be mitigated by the use of efficient storage technology, upgrading infrastructure and storage practices.

### 6.4.5 Chemical fumigation

Many countries use synthetic insecticides to control insects and pest for minimizing the storage losses. Developing countries are mostly using phosphine and methyl bromide for fumigation (Shaaya, Kostjukovski, Eilberg, & Sukprakarn, 1997). Phostoxin can be applied to dried maize grain (moisture content should be less than 13%) to control LGB (Larger Grain Borer) infestation. However, phostoxin has been applied by licensed technicians in various parts of Africa. Farmers can use Actellic Super which is a mixture of Actellic and permethrin (De Groote et al., 2013). Actellic Super application can avoid the pest infestation effectively for some months (Kimenju & De Groote, 2010). This chemical is widely used by farmers in Kenya and some African countries. In Tanzania, more than 93% farmers use it for pest infestation. Though the use of synthetic insecticides is very effective, but it has several drawbacks like cost, health hazard, environmental contamination and development of genetic resistance in the applied pests (Shaaya et al., 1997; Tapondjou, Adler, Bouda, & Fontem, 2002). The seed viability loss is more due to the interaction of residue coming from synthetic fumigants with seed (Shaaya et al., 1997). Some insect already developed resistance to phosphine in some developing countries because of its long use (Credland, Armitage, Bell, Cogan, & Highley, 2003; Villers, Navarro, & De Bruin, 2010). In developing countries, application of chemical fumigation to the traditional storage structures is challenging as they are mostly open to re-infestation. A precise dose of chemical pesticide and fumigant should be applied at the proper time. Therefore, the farmers need to be trained with proper technical knowledge, which is the main challenge in developing countries. Incorrect dosage, delayed treatment and adulterated chemical can adversely affect the storage.

### 6.4.6 Natural insecticides

Many plant species have natural ability to protect the grains from pests and insects and it is used as a traditional practice in several Asian and African countries. Plant and chemical based products are biodegradable, eco-friendly and nontoxic for human health. The Chenopodiaceae plant leaves and oil extract control the cereal grain damage caused by the insects (Villers et al., 2010). R. Kumar et al. (2007) investigated the effect of wormseed essential oil against the fungal deterioration in stored wheat at laboratory conditions for 12 months and found that the essential oil was effective in A. flavus fungi control in both inoculated and uninoculated wheat samples. The essential oil is more effective than synthetic fungicides like ceresan, ziram, benomyl and diphenylamine even at minimum concentration. Shaaya et al. (1997) studied the effect of four edible oils (pure and crude cottonseed oils, pure soybean oil, crude palm kernel oil, crude rice bran oil) as fumigants in wheat and bean and found that both crude rice bran oils and crude palm kernel effectively controlled C. maculatus in chickpea during first 4 to 5 months. Soya bean and crude cotton oil are effective against S. oryzae in wheat in the first 4 to 5 months, and later it is effective at relatively higher concentrations (10 g/kg). Only crude oil controls S. zeamais in maize during the initial period of 4 months. After 8 months, oil becomes partially effective as a number of insect increases (20%–40% of untreated maize samples). Commercialization of plant material as an insecticide is becoming difficult as it is expensive. However, some plants of low cost can be used as a natural insecticide.

### 6.4.7 Hermetic storage

Hermetic storage (HS) is also known as “airtight storage” or “sealed storage”. This method is used to store cereals, coffee, cocoa beans and pulses in developing countries because of its cost-effectiveness and avoidance of the use of pesticides and chemicals. In this method, a modified atmosphere of high $CO_2$ can be created by using sealed waterproof structures. Inside the airtight structure, the grains respire and creates high concentrated carbon dioxide atmosphere which helps to attain high $CO_2$ concentrated atmosphere (Tefera et al., 2011).

Airtight storage structures are very effective in preventing storage losses (Adler, Corinth, & Reichmuth, 2000). This storage structure is easy to install, limits the pesticide use and it is economic which makes it more effective (Initiative, 2014). Several factors affect the respiration of grain inside the storage structure. The airtight storage structure uses carbon dioxide concentration as an indicator of grain’s biological activity (Cardoso et al., 2008). High moisture content increases the carbon dioxide concentration because of the increased rate of respiration (Bartosik, Rodríguez, Cardoso, & Malinarich, 2008). Action Research Trial by World Food Programme (WFP) in Burkina Faso and Uganda, found that airtight structures are very efficient in killing the insects and pests by themselves without using phosphine fumigation (Costa, 2014). Purdue Improved Cowpea Storage (PICS) bags, metallic silos and super grain bags are various hermetic storage structures that are developed and promoted in recent years. Because of the practical consideration and cost-effectiveness, this storage technology is gaining popularity in many countries (Zeigler & Truitt Nakata, 2014).

Metal silo is a cylindrical strong airtight container and has been built from galvanized steel sheet, is cost-effective for storage of grains for a longer duration of time by preventing the grain from rodents and insects. In some places, painted aluminum is used for making silos which improves the appearance by preventing corrosion (Yusuf & He, 2011). This structure cuts off the oxygen level and hinders the metabolic pathways of weevils, which kills them by preventing water production (Murdock et al., 2012). Storage loss in traditional storage structure is significantly higher than the modern storage structures, and minimum loss is found in case of metal silos. Another research study based on postharvest losses of rice in China showed that 7 to 13% grain losses at the rural household storage facilities, compared to only 0.2% losses at the national reserve level using scientific storage structures (Qiu & Jin, 2003).

Several other research studies revealed that metal silos are effective for storage. However, the major problem associated with metal silo is its capital cost. Community-level silos can be taken as an alternative to the metal silo as the cost per unit grains is low compared to metal silo as the size is small. This silo has very low maintenance cost which can be helpful in compensating the initial cost to a great extent. Kimenju and De Groote (2010) studied that advanced storage structures are economical than polypropylene bags. However, the initial cost of metal silos is more than polypropylene bags.

Storage of grains in hermetic bags is difficult, as grain has to be dried thoroughly before storage. Latin America and Russia use Super Grain bags to store coffee. These bags are most popularly used in Nepal for corn, Afghanistan for wheat and in Vietnam for rice conservation (Ben, Liem, Dao, Gummert, & Rickman, 2009). Latin American countries used those bag to store the grain crops without pesticides application (Zeigler & Truitt Nakata, 2014). Modern technology can significantly reduce storage loss in improved storage structures. However, smallholders training is equally important like technology dissemination (Kitinoja, 2013). The government organization should provide training in local language regarding the use and maintenance of this technology so that it can be widely practiced.

## 6.5 ROLE OF PACKAGING IN FOOD SECURITY

Ensuring food security by reducing worldwide food waste and losses is the prior point to focus. Packaging could act as a key player for ensuring food security. Packaging plays a major role in containment and protection of food in the supply chain of the food product (Ahvenainen, 2003). Packaging reduces food wastage during storage and transport, and the primary goal of packaging is sustainability. Packaging provides resistance to the external factors that hamper the products. The main purposes of packaging are to stabilize and protect the food until consumption (Barton, 2018). The adjoining functions are communication, marketing, and distribution. The packaging also ensures the integrity of food, to resist exposure to physical damage like deteriorating environmental factors like dust, light, microbial and chemical contamination or mechanical shock (Killoran, 2018). Inclusively, the packaging systems are supposed to maintain the nutritive value, sensory attributes and provide safety from foodborne pathogens or endogenous pathogens. Severe post-harvest losses take place due to the improper packaging method adopted. Losses continue due to the inefficient packaging system, right from harvesting to retailing or until consumption (Ericksen, Ingram, & Liverman, 2009). These losses happen due to the insufficient knowledge by the stake-holders regarding appropriate packaging method (Coussy, Guillard, Guillaume, & Gontard, 2013).

## 6.6 PREVENTION OF POST-HARVEST LOSS BY PACKAGING

Food security prioritizes on reducing the global food wastage and losses. Appropriate packaging can ensure food safety by following methods and management practices (Duncan, 2011; Espinosa, Castillo, & Barbosa, 2017; Han, 2003):

i. Improving food preservation which reduces storage and transportation loss, by overcoming cold chain problems with modified atmospheric packaging.
ii. Reducing the impact of packaging material on the environment, by overcoming waste-management problems with eco-friendly packaging.
iii. Concerning on social, economic and environmental sustainability of food, by using decision-making tools to design or select appropriate food packaging.
iv. Use of appropriate and efficient packaging permits to limit the loss of waste and food.
v. Use of distribution packaging, which provides better shelf life and protection for fresh agricultural produce as it moves from farm to processing, wholesale and retail unit. Also, the distribution packaging ensures recovery of unsaleable and surplus fresh agricultural produce from farms and redirecting to food rescue organizations.
vi. Shift to processed and pre-packed foods to reduce the wastage during distribution and extend the shelf life until consumption.
vii. Proper design of secondary packaging, ensuring that it protects the food products during transit through the supply chain.
viii. Advanced packaging materials like controlled and modified atmospheric packaging, oxygen scavengers, anti-microbial packaging to extend the shelf life of the products.
ix. Training the retailers, manufacturers, and consumers regarding the terminologies used in packagings like best-before and use-by. This can ensure that the products are used appropriately and not discarded away when it is safe to eat, due to insufficient knowledge.
x. Packaging design to cater for altering consumption patterns and households. Small serve products can reduce the wastage for individuals or two person households.
xi. Proper communication and collaboration between retailers and manufacturers to convey the consumer’s preference and food wastage in the supply chain. Industry’s understanding on this issue can track the root cause of the problems regarding wastage, which in turn can reduce the environmental impact on waste and reduce the cost.
xii. Intelligent packaging with synchronised supply chains that can share data reduce out-of-date or excess stock.

Retail ready packaging to minimize double handling and damage also to improve stock turnover.

## 6.7 CONTROLLING FOOD SAFETY IN FOOD SUPPLY CHAIN

A food safety management system, therefore, is vital for ensuring the safety and quality of foods prepared for consumers. An improvement in food safety control systems can significantly reduce microbial contamination of foods throughout the food supply chain (FSC). Therefore, it is necessary to understand the ways to manage the FSC for improving microbiological food safety. Currently, different food industries apply different food safety controls in their safety management systems, and the functioning of such systems also varies. To ensure sustainable control of product quality it is important to have a well-managed operation at each step within the FSC. In many countries, including Australia, processed and ready-to-eat meats are potentially a vehicle for foodborne illnesses associated with *Clostridium perfringens, Salmonella, E. coli* (EHEC) *and L. monocytogenes.* Development of risk management systems and the implementation of HACCP based food safety strategies across the FSC for different food products are essential for all countries to reduce food poisoning outbreaks and improve global food security.

Applying HACCP or a similar system of hazard control in food manufacturing business is important to control hazards and, thereby, improve the safety of food. Nevertheless, many recent studies have suggested that a combination of two or more safety control programmes, such as the International Organization for Standardization (ISO) quality management system, good manufacturing practices (GMP) and HACCP, markedly improves microbial food safety management and, thereby reduce food contamination. Implementing one or more of these systems during food production is therefore widely recommended for food manufacturing businesses to achieve more effective food safety management to improve food security (Elkhishin, Gooneratne, & Hus-sain, 2017).

## 6.8 CONCLUSION

Food security is the accessibility of the food to all individuals worldwide. Food safety plays a major role in the food security. Due to the failure in maintenance of food safety, the severity of food insecurity is increasing. One of the prime reason for not maintaining the food security is post-harvest losses. Storage and packaging losses are the vital problems prevailing in post-harvest operations and it affects the livelihood of farmers. Use of advanced and appropriate technology for storage and packaging depending upon product can reduce the loss even below 1 to 2%. Proper training and knowledge about food safety to the manufacturers, wholesalers, retailers and consumers can ensure food security, globally.

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# Chapter 7

# Food security: Role of Technology and Innovation

**Satakshi Aggarwal and Rachna Sehrawat**

## Contents

## 7.1 INTRODUCTION

The WHO states food security is when the population get the access to safe, nutritious and sufficient food at all time, to have healthy life. Food security is an ambiguous topic especially in developing countries. Tons of foods gets wasted all around the world from different sources such as in supply chain from postharvest losses, manufacturing processes, spoilage at retailer's point hence leading to food scarcity and increased food prices globally. Currently, the demand for food has increased globally causing various risks and challenges to meet these demands and keep global agro-food system sustainably.

Increased in world population, since 1980 to 2000, the entire population has elevated from 4400 million to 6100 million, inflicting 50% rise in the global production of food. Population has increased at a rate of 2% since 2000, crossing 7.3 billion in 2014. It is speculated that world population may hike to 9.7 billion by 2050.

Apart from manual losses, climate change i.e., fluctuation in atmospheric temperatures, increased $CO_2$ proportion and precipitation variations also affect the agro-food production. These nature-based factors sometimes may cause draught leading to no crop growth in the current season.

Around 1.3 billion tons of food i.e., one-third of total production gets wasted all around the world through the supply chain that includes post-harvest practices (storage and handling), agricultural practices, processing measures, distribution and during food preparation. There is an endless requirement innovation and advancement in persisting technologies to facilitate the increasing demand of sustainability, supply chain & food security.

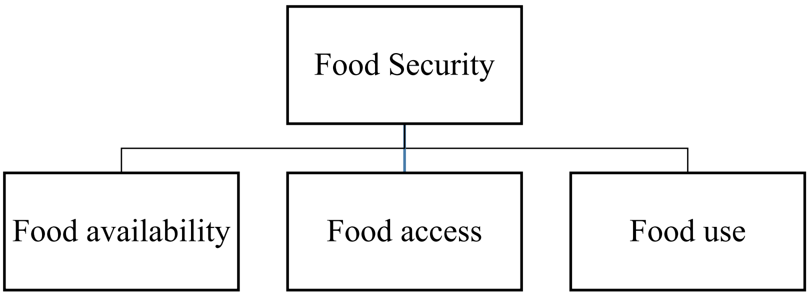


**Figure 1:** Classification of Food Security

## 7.2 TECHNOLOGY

### 7.2.1 Nanotechnology

Nanotechnology has grown at a very faster rate since 10 years and the demand for employing nanotechnology is consistently expanding. It can be defined as assembling single or group of molecules or atoms inside the structures for developing enhanced properties. Mechanisms of nanotechnology is based on modifying the appliances or matter which have at least 1-D approx. 1–100nm in size (length). Physicochemical characters of a materials at nano - scale gets appreciably modified in comparison to those at macro-scale. Functional and nutritional compounds and ingredients i.e., vitamins, flavours, colours, antioxidants, polyphenols are important comoponents in foods commodities; however, they get degraded substantially during processing. New emerging techniques i.e., nano-encapsulation and nano-emulsions are carried out to protect hypersensitive bio-active compounds and to increase their bioavailability in final food products. Use of gelating agents, anti-caking agents, and contaminant sensors are some other applications of nanotechnology in food and packaging materials.

**Nano-sensors:** People expect good quality product at a very low cost therefore, becoming a challenge for marketing food products. These sensors are employed to spot pathogens like *Salmonella* and other toxic compounds in the food supply chain. Several dyes and nanoparticles are used in these sensors to detect changes i.e., release of gases from products, detection of oxygen, etc. Sensors have wireless networking system which provides data to the product manufacturers and maintain the freshness of food throughout the supply chain.

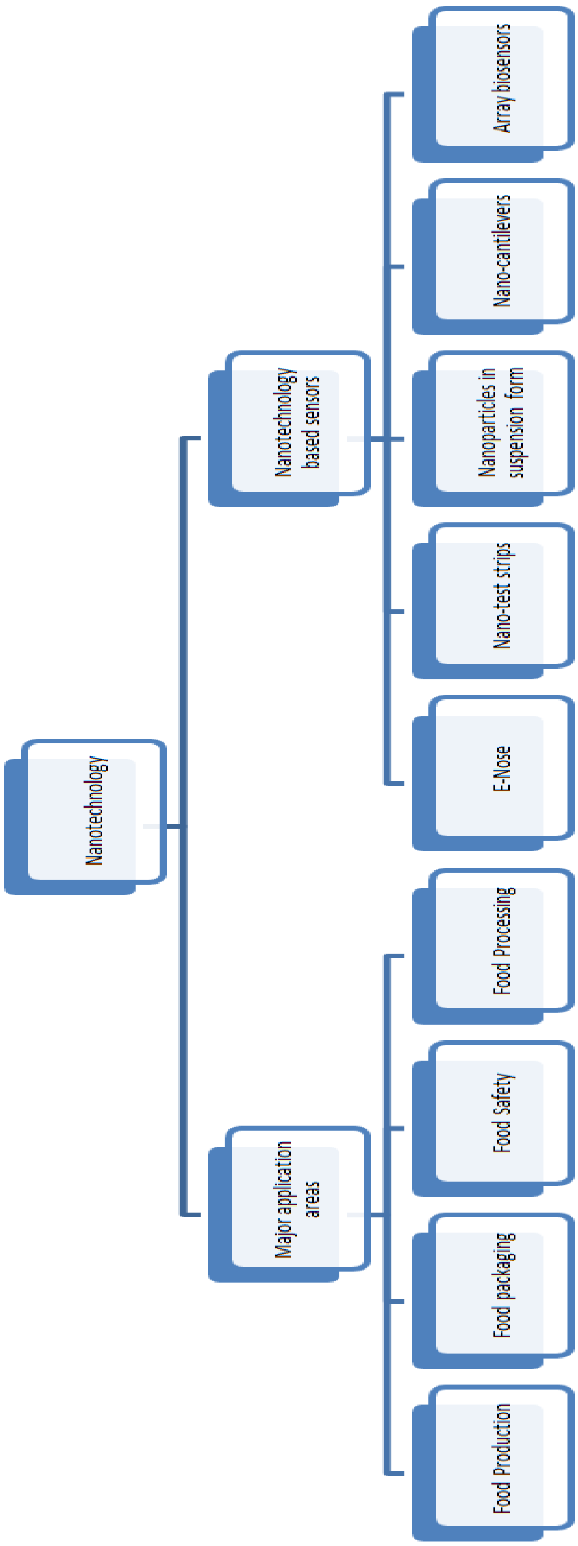


**Figure 2:** Nanotechnology and Nano based sensors

**Table 1:** Application and impact areas of Nanotechnology in Food technology.

| Application of Nanotechnology | Impact Areas |
|---|---|
| Food Safety | Edible coatings<br>Nano-packaging |
| Nano sensors | Pesticide detection<br>Toxin detection<br>Pathogen detection |
| Packaging | Edible coating<br>Intelligent packaging<br>Active packaging |
| Nano-encapsulation | Bioactive delivery<br>Flavor delivery<br>Nutrient delivery |
| Enhance physical properties | Color additives<br>Anticaking agent<br>Increase tensile strength<br>Increase gas permeability<br>Increase water resistance and flame resistance |
| Against biological deterioration | Antimicrobials<br>Increase bioavailability |

### 7.2.2 3D-Printing

3D-food printing is one of the most effective approach to deal with world food insecurity difficulties by assimilating alternative sources of protein or wild plant resources into production of wholesome food choices. This not only overcomes waste for food producers but also enhances culinary innovations and customizes the commodities depending on the nutritional needs of a specific individual.

Dysphagia is a condition that leads to difficulty in swallowing of food which majorly affects older adults. 3D-food printing using food ingredients has become an alternative solution to many problems (Rifkin, 2011).

At present, several nursing homes in Germany already use 3D-Printing technology to generate food known as smooth food for citizens who undergo treatment for dysphagia. This technology makes the food more appetizing (Murphy and Atala, 2014).

3D food printing is also called as "Press Print and Eat". This technique is found with number of advantages i.e., i) resolving food scarcity issues, ii) reducing chances of malnutrition, iii) subduing climate change, iv) dropping unnecessary businesses, and v) working on problems for food to be supplied to astronauts and military personnel (Huang et al., 2016). 3D food printing is an easy and quick approach to prepare food. It eliminates the production steps of food processing which permits the manufacturer to concentrate further on developing ingredients. Once the food production process concentrates solely on producing the food ingredients that go into the 3D food printer, helps to overcome the challenge to make enough food. However, it solves the problem of food scarcity problem.

For more enhanced and potential results from 3D food printing to tackle malnutrition is to develop nutritionally enriched products in order to cater the requirements of people, i.e., their recommended everyday value. As food printing skips the processing steps like cooking or microwaving which decreases human efforts and eliminates the problems of charring of food samples. It also avoids contact of consumer to lethal radio and microwaves (Ford and Despeisse, 2016).

### 7.2.3 Pulse Electric Field

Pulse Electric Field (PEF) comprises of 4 main components: i) power supply (high voltage), ii) capacitor, iii) pulse generator, iv) control and monitoring system and v) treatment chamber with electrodes. Gaps between the electrodes is filled with aqueous sample which is to be treated. Food being a complex multiphase component exhibit dipole moment which leads to formation of net charges. These electrochemical properties of foods possess vibration (dipolar), rotation, reorientation and translation when exposed to electric fields. Changes in molecular conformation leads to decrease in bioactivity of proteins. Modifications in constituents, sensitive to electricity on application of external electric field enhance the heat and mass momentum, which increases permeability through membranes when high intensity PEFs are induced.

## 7.3 INNOVATIONS

### 7.3.1 Lab on a Chip

Food being an essential need for humans get easily spoilt microbes causing several foodborne illnesses. *E.coli (O157:H7), Salmonella spp., Campylobacter jejuni, Staphylococcus aureus* and *Listeria monocytogenes* are most common foodborne pathogens that are found in different food products from many past decades. Poor availability of compact and real-time biosensors for the detection of pathogenic microbes led to significant time lag between the first outbreak and its identification. The time lag can also be caused due to delivering samples to remote labs (1-2 days); and subsequent analyses in the labs taking from few hours to a couple of days.

Sometimes, the remedy for contamination from pathogens is not acted upon unless there is an outbreak detected at post-customer level. Lab-on-a-chip has become a recent approach suggested by scientists which act as an appropriate mode for compact and real-time bio-sensors.

A lab-on-a-chip basically handles a small volumes of fluid which deals with the manipulation of fluid behavior and precise control that are constrained to a millimeter scale. Lab-on-a-chip technology employs a channel networks that are inscribe over glass, some polymer chips or silicon to make mini-labs.

As per studies conducted by Yoon and Kim (2012), there are very less time required for detection of foodborne illness caused by mycotoxins and pathogenic microbes. The progress of such devices provide automatic functions for rapid detection of mycotoxins and pathogenic microbes with better sensitivity. This chip technique is mm or cm in size which can be incorporated in agro-based and other food products. This lab-on-a-chip helps better handling of samples, staining, electrophoresis, dilution and detection on a single integrated system. The major benefits of lab-on-a-chip are: easy to use, fast analysis, less sample requirement, and high reproducibility due to automation and standardization.

### 7.3.2 DNA barcoding

At time, mislabeling, adulteration and food fraud can also occur in food products. DNA barcoding is a recent advanced technique for food traceability which involves comparison of short genetic mark-ups over the food sample with a reference DNA sequence. The United States- FDA suggested that seafood is one of the immensely traded product which often faces mislabeling. This technology assists in determination of the true identity and the authenticity of the material source. In order to avoid mislabeling, misbranding issues and false claims by manufactures certification programs like TRU-ID has also been developed

Rice, rye, corn, barley, sorghum, etc. are the major crops cultivated which have been tested with PCR-methods. Such methods are beneficial for both the groups i.e., one who is interested in protecting and the other one for certifying their crops. A multiplex DNA micro-array chip for detection in GMOs, has been developed in recent years.

Seafood commonly including aquatic living organism i.e., crustaceans, fish, echinoderms and mollusks have been successfully applied DNA barcoding because: (1) aquatic life forms are higher in number in comparison to other animals like cattle, sheep, etc. hence increasing the effectiveness of the technology; (2) many foods such as processed products lack in authentic identification approaches; (3) detailed molecular identification is possible in seafood than other living forms which can analyze more than the species level. DNA fingerprinting technique used in plants identification can be easily replaced by DNA barcoding with a higher effectiveness.

There is no requirement of extensive and detailed knowledge of genome of each organism in DNA barcoding, hence making it more desirable method to be used globally. This technology has also shown effectiveness for identifying the allergic species in food products based on presence of marker genes. For ex. it is easy to identify presence of allergic components found in fresh and processed nuts samples.

### 7.3.3 Protein utilization

It has been estimated that global market demand by 2050, will be increased by two folds for animal-derived protein, hence creating the concerns for wise utilization, sustainability and food security. Sustainable issues have arrived because it is believed that animal-based food products emit a greater level of global warming gases in comparison to plant-based products. It is also assumed that raised demand for animal-extracted protein would lead toward rise in the need for more land for animal feed purpose which would in turn cause transformation of forests and natural grasslands into farm lands, again increasing the GHG emissions. Major plant-based protein source (wheat, rice, corn, soy, potato, etc.) utilization can overcome the rising trade of animal-based protein sources, hence eliminating the negative impact on the environment (Westhoek, 2017).

However, all proteins differ from one another i.e., they differ in nutritional characterization, digestibility and bio-availability, environmental entanglements, consumer acceptance, and other factors.

Many plant-based products have already become an alternative to meat in the market. Quorn is one of such product founded in 1985, obtained from fungi by natural leavening process and wheat-originated glucose syrup. Quorn Foods, sells approximately 24250.849 US ton of Quorn in around 16 nations, in order to increase production potential in their UK industry.

Utilization of reverse osmosis membrane technologies i.e., micro- and ultra-filtration has produced versatile holdings of protein ingredients in dairy industries, including altered functional and nutritional properties, developing other various forms for an extensive type of foods around this world.
By-products in dairy industry such as lactose and mineral salts are removed. Treatments such as ultrafiltration of skim milk produces milk protein concentrate (MPC) and milk permeate and whey protein concentrate (WPC) and whey permeate and generated on filtration of whey. The market of whey protein around the globe is continuously growing due to the high demand for nutritional enriched food. Microfiltration of milk has helped in the development of new protein ingredients to design micellar casein protein and native whey (Vergé et. al., 2013).

Global whey market is surrounded with some other specific portions such as alpha-lactalbumin, beta-lactoglobulin, Lactoferrin, Immunoglobulins (IgG), Lactoperoxidase and Glycomacropeptide (GMP) producing an application in nutrition to infants, medical and sports refreshments. As per some recent investigation conducted, whey proteins play a role in maintaining muscle mass which provides additional possibilities for extension of whey protein in the global businesses.

On a global base, plant-based sources and insects have become an important topic for protein. Species such as beetles are majorly consumed insects upto 30-31%, caterpillars 16-18%; followed by 14.0% of wasps, bees and ants; grasshoppers, locusts and crickets leads up to 13.0%, leaf-hoppers, plant-hoppers, scale insects and true bugs up to 10.0%; termites ≈3.0%; flies 1-2%; and miscellaneous 5.0%. However, currently researchers found that insects are a secondary option of protein for western countries and not only as crisis nutrition, supported by FAO and the European Commission (Van et. al., 2013).

Insects require no land, less water and emit less amount of GHG and NH3 than other animals. They breed on organic side-streams leading to less production of waste products. However, insect production also depends upon the insect's intake, which determines whether it can be used as food or feed sources. One of the environmental benefits is that relevant to 80.0% of body weight is palatable and absorbable in comparison to 55.0% for chicken and 40.0% of red meat. Nutritional profile of many insects are favorable to humans, among which most are extremely absorbable (76.5–98.5%); high in crude protein 40.0–75.0% on dry weight basis and also an appreciable root of quintessential amino acids, good in vitamins such as Thiamine (B1), Riboflavin (B2) and Niacin (B3) and appropriate amount of minerals (Fe and Zn). Some food products are available in the market such as sports protein bars which has been developed by the British firm, Next Step Foods.

Marine plants like seaweeds and microalgae are also an assuring and new ultimate protein source. Currently, 6.4 BT of algae especially seaweed is grown over the world (Fleurence, 1999). Arthrospira spp. (Spirulina spp., viz, cyanobacteria), Chlorella spp. and Dunaliella salina is the major micro-algae utilized for human consumption to fulfil the need for alternatives of protein sources other than animal-based sources. Majorly, the protein portion of brown seaweeds is less (3.0±15.0% of the db weight) in comparison to green or red seaweeds (10.0±47.0% of the db). Seaweeds can additionally be applied in aquaculture nutrition or as animal fodders.

**Table 2:** Classification and sub-classification for protein utilization.

| Sources | Sub-classification | Product Formed | Process applied |
|---|---|---|---|
| Plant-based | fungus | Quorn | natural fermentation process<br>wheat-derived glucose syrup |
| dairy-based | skim milk<br>Whey | milk protein concentrate (MPC)<br>whey protein concentrate (WPC)<br>micellar casein protein | Ultrafiltration<br>Filtration<br>Microfiltration |
| Marine plants | Seaweeds<br>microalgae | soybean meal | Cultivation |

In vitro meat or cultured meat is prepared from animal product by isolating the cells and classification, followed by cell culture and tissue engineering etiquettes. Technical problems persist, while generation of in vitro meat i.e. uncertainty in growth of cells which might leads to cancerous cell development. The structure of the culture medium requires to meet the necessities of growing cells and be counted safe for consumption. The major problem among the production of in vitro meat stocks is the complexity of circumstances which add to the definitive eating quality of authentic meat.

### 7.3.4 Genomics

Nutrigenomics is a study that defines the response of any specific genes in any food product and vice versa. This study helps in prevention of disease, disease mitigation and methods for treating chronic disease as it helps to fulfill any person's specific nutritional requirements depending on their genotypic information.

Several advancements are done in processing and formulation technologies for final product development from raw sources as per consumer demands. Molecular genetics and animal breeding has become the field for continuous development and research, over the past few decades. This has led to accelerated progress in genetics and increased preciseness towards selection of the superior genetic stock. Commercially available single nucleotide polymorphism (SNP) chips have been generated for genomic selection purposes (Blasco & Toro, 2014).

The apparent inconveniences have drawn attention for more research towards these studies leading to further modifications in fatty acid composition of oil seeds. Breeders and biotechnologist have worked together to enhance the oleic acid concentrations in palm, canola, sunflower, peanut, cottonseed, safflower and soybean 36% to 59%, 57% to 89%, 29% to 8 %, 55%to 76%, 13% to 78%, 10% to 81% and 24% to 84% respectively (Wilson, 2012).

### 7.3.5 Aquaculture

Aquaculture is a technique in which water life forms and harvested and breeded in both fresh and marine water. This sector involves nearly 200 fish species which are cultivated via pens, cages, rain-fed ponds, and irrigated systems. (Bostock et al., 2010). Due to poor management from past many years it has led to over-exploitation of aquatic flora. Also, in past 20 years, growth rate of aquaculture has reached up to 8% annually. Aquaculture is an essential technique for supporting low and medium income sections of countries where fish is a staple food (Bunting et al., 2015). Due to the increase in employment of low-income group people towards aquaculture, it has led to increase in contribution to their food and nutritional security, both directly and indirectly.

According to the FAO, fish is the primary protein source for more than 1 billion of population. On an average 16.1kg/capita is the annual fish consumption around the globe. South-East Asian countries produce fish majorly for local consumption. Due to advancement in aquaculture technology, consumption of protein from animal sources got doubled in past 3 decades in developing countries. People below poverty line have no access to enough of nutritious food for their better health (Wahab et al., 2011). Cereals and other low-cost staple ingredients are the majorly food bought from the market whereas meat and fruit vegetables lies out of the budget limits for low income groups.

Fish produced from aquaculture are cheaper in price than that of animal meat. They are high in protein, vitamins and minerals. Nearly 50 crores population of developing countries dwell on aquaculture for living. Less access to transportation and poorly developed infrastructure is a question to its effectiveness. (Beck and Villaorel Walker, 2013). But in today's time, increased social and financial assistance has acted as a driving factor in successful aquaculture production. Intensive aquaculture is notably a high risk operation because a failed harvest leaves for no other alternative for income source. Another major challenge, limited access to markets, particularly in urban centers restricts the aquaculture enterprise.

Cost of fish is high in urban areas and proper access to these markets by farmers can greatly influence potential their income generation. Also in some regions middle-men are employed for selling fishes to the markets. Due to no access to urban markets for selling fish at an optimum cost, farmers are forced to sell the product to middlemen who sell the aquatic life forms in urban market at much higher prices (Havel et al., 2015). Governing bodies need to increase the facilities for local farmers to access the urban markets to increase profit margins.

FAO defines commercial aquaculture as those farming operations of fish whose goal is to earn maximum profits i.e., revenues minus costs. Currently, it is estimated that the global fish has a trade of US$56 billion, exceeding most of the conventional agro-based exports. Commercial aquaculture contributes undoubtedly to food security, providing job and income generation in developing countries.

Proper availability of electricity and potable water supplies and good quality of roads for transportation will enhance the commercial aquaculture, hence increasing the income sources for farmers. Waste reduction is another key component in this process.

Equalizing the availability of feed and utilization of cultured animal and simultaneous removal of waste are the major components in maintaining productive systems. Aquatic feedlot systems, where all feed requirements are supplied by exogenous feed, are of increasing importance globally.

The major aspects to maintain the water quality are to ensure adequate amount of dissolved oxygen are high and nitrogenous compounds should be below to the critical limits. Use of cages depends upon the dilution with water for maintaining the adequacy in water quality, pond managers can also employ a range of tactics that includes aeration and water exchange. Removal of solids is another major component for maintaining the quality of water. Ozonation is another key process that is used to oxidize organic molecules and nitrite compounds and sterilize the process water. UV lamps are also exploited for sterilization process of water and reduce the risk of diseases that get introduced from incoming water.

## 7.4 CONCLUSION

Food security comprise of 3 main components food access, food use and food availability. To overcome the challenges to food security several technologies and innovative techniques are being employed around the globe. Nanotechnology i.e., nanosensors are employed to detect pathogens such as *Salmonella*. Another technology such as pulse electric field and 3D- printing has also helped in overcoming the challenge against food security. Food printing skips the processing step which reduces the human efforts also. Innovative techniques such as Lab-on-a-chip, aquaculture, DNA barcoding, etc. has also played an important role for increasing food access to low and medium income groups of the country.

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# Chapter 8

# Laws and policies regarding foods

**Somya Tewari and Rachna Sehrawat**

## Contents

## 8.1 INTRODUCTION

Food loss or waste is rapidly and surely becoming one of the gravest issues facing the world right now. To make it a little easy to understand the gravity of situation, have a look at the data below, which has been summarised from a study "A Global Snapshot of Solid Waste Management to 2050"by World Bank.

The study states that "at international level, the largest waste category is food and green waste, making up 44 percent of total global waste". To further break this data down, following is a table.

**Table 1:** Percentage of food and green waste produced in different regions of world in comparison to the total waste produced.

| Region | % of food and green waste out of total waste |
|---|---|
| East Asia and Pacific | 53 |
| Latin America and Caribbean | 52 |
| Middle East and North Africa | 58 |
| North America | 27 |
| South Asia | 57 |
| Sub-Saharan Africa | 40 |

This chapter tries to quantify the seriousness of the situation, by beginning to define distinctly food loss and food waste, and gradually builds on in the direction of focusing the very many causes behind such huge quantity of food going waste. The chapter is also an attempt to collate a lot of studies, reports and data being generated by FAO, World Bank, various development organisations and public institutions with a motive to deliver a quick reference on the food waste and loss quantum, the factors responsible, an elaborate summary of government legislations that encourage food waste, steps that are already being taken around the globe towards reducing the food waste and the way forward.

A thorough study of numerous reports, articles and research happening around the world clearly suggests that a lot is happening in community silos and that each initiative taken in this direction has a concept, understanding and matrix of its own, which makes it all the more difficult to summarise and quantify the impact of these initiatives collectively. There is clearly a lack of systematic literature review and consecutive study of the initiatives launched in order to fight food loss and waste, which restricts the larger population to benefit from a strategic plan which has proven effectiveness.

With a focused approach on the impact of certain food legislations and policies on the generation of waste and the possible solutions coming out of designing the policies in the right way, the chapter concludes as an initial small step towards the larger goal of achieving food sustainability.

## 8.2 FOOD LOSS AND FOOD WASTE

Food is one of the essential resources that cannot be overlooked while considering sustainability. While we talk about sustainability, which means the ability to maintain a resource at a certain level, food sustainability would translate to maintaining the input versus output of the edible products at an optimum level so as to sustain human life. This is where food loss and waste form an integral part of the equation. The term “loss” and “waste” might have been used interchangeably in the past but off late have been distinctly defined.

According to FAO, “food loss refers to the decrease in edible food mass available for human consumption throughout the different segments of the supply chain”, which includes the quantitative loss due to deterioration of quality ultimately leading to a loss of economic and nutritional value. On the other hand, “food waste refers to food losses resulting from decisions to discard food that still has value”, which essentially means willingly letting the safe and consumable foods go unconsumed and spoil. The consumer and retailer behaviour have a lot to do with food waste.

Diving deeper into the definitions helps us locating the most probable stages where food loss and food waste can occur in the life cycle of foods. It can be inferred in the case of food loss, that it is unintentional, and is likely to occur due to unavailability of suitable infrastructure and logistics during agricultural production, post-harvest, and processing stages of the supply chain. As opposed to the former, food waste is more likely to occur at the later stages of food supply chain i.e. during distribution, sale, purchase and consumption (FAO, 2011). Between the two, food waste is relatively easier to address since, it is more often than not, a choice translated into behaviour, mainly observed as an outcome of the urbanized lifestyle.

According to FAO reports, about a third of the total food produced in the world for human consumption every year — approximately 1.3 billion tonnes — gets lost or wasted. And globally, with 45% of total “fruits and vegetables” and “roots and tubers” being wasted every year, these categories constitute the highest wastage rates as compared to other food categories, followed by “fish and seafood” and “oilseeds and pulses”, where 35% and 22% of the global production is either lost or wasted respectively. While 46% of food wastage happens downstream, i.e. at the processing, distribution and consumption stages, the rest 54% is taking place as food loss in the upstream section of food supply chain.

To look at it economy wise, it is observed that medium- and high-income countries are, to a great extent, responsible for wasting food (without ruling out the possibility that a large amount of food is also lost during production and processing) amounting to 31-39 percent of total wastage, and in the low-income countries food is mainly lost, owing to the lack of adequate and appropriate infrastructure in the initial and middle stages of the supply chain. This is also demonstrated in a study conducted by Gustavsson et al. (2011) estimating the food waste in Europe and North America at 95–115 kg annually, in comparison to 6–11 kg annually being wasted in Sub-Saharan Africa or South/Southeast Asia.

**Table 2:** Global Estimates of Food Loss/Waste (FAO, 2011)

| Food Category | Estimated Loss/Waste (%) |
|---|---|
| Roots and Tubers | 45 |
| Oilseeds and Pulses | 22 |
| Meat | 20 |
| Fruits and Vegetables | 45 |
| Fish and Seafood | 30 |
| Dairy | 20 |
| Cereals | 30 |

**Table 3:** Food Loss/Waste estimates for different countries of Europe (Food Waste, Causes and Impact, 2012 (Barrila Centre for Food and Nutrition))

| Country | Food Loss/Waste (million tonnes) |
|---|---|
| United States | 33.7 |
| Great Britain | 7.2 |
| Germany | 6.7 |
| Italy | 6.6 |
| France | 6.3 |
| Sweden | 0.7 |

## 8.3 IMPACT OF FOOD WASTE

It is needless to point out the huge economic losses cast by the loss/wastage of 1.3 billion tons of food, which roughly amounts to a retail equivalent of $1 trillion of food each year, which does not include an estimated $700 billion invested in the natural resources such as water ($172 billion) and cleared forest area ($42 billion, because food waste and loss also implies the waste of all the resources that went into producing it. For instance, in the United States, 25 percent of the country's water use is accounted under food waste. Food waste or loss also adds about 3.3 billion tonnes of greenhouse gases to the planet's atmosphere, which amounts to $429 billion (included in the $700billion for natural resources).

But, it is just not the economic impact of food waste that we should be worried about. There are environmental and social costs too. The later a food product is lost along the chain, the greater the environmental consequences. Thus, broadly the impacts of food loss and food waste can be categorised into

a) Environmental Impact
b) Economic Impact
c) Social Impact

The environmental impact can be estimated only after tracking the selected food through its entire supply chain and taking into account its carbon footprint, water footprint and ecological footprints (Venkat, 2011; WRAP 2011). The fruits and vegetables we throw away, scraps with them the amount of water used to produce, clean and maintain them and the carbon footprint that the unconsumed agri-produce leave behind during its entire lifecycle.

In order to calculate the economic cost of the food loss or waste, we need to take into account either the production cost (the cost went into obtaining the product) and/or the market cost (the market price of the individual product at the time of wastage). To this, we also need to add the negative value that society has to pay in the form of environmental impact of food wasted and the cost of land used to grow the particular produce. Only after due consideration of each of these costs will be able to quantify the economic impact that the loss or wastage of one particular commodity has (Segrè and Falasconi, 2011). And lastly, the social impact of food loss or waste can be explained by a simple finding of the FAO study stating that the quantity of food that ends up in the garbage in industrialized countries (222 million tons) is nearly equal to the avail - able food production in Sub-Saharan Africa (230 million tons). The social impact thus, can be explained best by the term “food insecurity”.

## 8.4 REASONS BEHIND FOOD LOSS AND WASTES

### 8.4.1 Microeconomic drivers

The microeconomic drivers, contributing to food loss, generally include loopholes in the value chains such as inadequate storage, missing markets or limited access to markets, out-dated technology for harvesting, storage, or processing and/or lack of technical knowledge or lack of access to technical knowledge; lack of infrastructure for transportation of food over long distances; slow or nil technology innovation.

At the same time, food waste owing to microeconomic drivers largely is a result of retail and consumer behaviour, such as low planning capacity of warehouses and retail stores, certain modified values guiding consumer choices or new preferences in food based on aesthetic characteristics, social status/ prestige etc., or preference for precooked or RTE food; relationship between low purchasing power and the consumption of low nutritional food high use of precooked and ready to eat products; portion size and lack of information related to food labels, standards and expiration dates.

### 8.4.2 Macroeconomic conditions

a) Employment structure: A decline in the work force engaged in the agricultural sector; loss of labour force engaged in the post-harvest segment of the food supply chain, and high labour cost leading to a staff reduction employed in managing the FIFO for retail stores and other food selling platforms, which ultimately contributes to inefficient management of food, resulting in it being wasted.

b) Trade and globalization: With globalization of supply chains, distances between the producers, processors and consumers have increased, resulting in rising complexity in logistics. The imports of processed food commodities have, on the other hand, impacted the fresh local foods negatively. The rising global quality standards, with the amount of money invested in maintaining it, have also decreased the popularity of various locally available foods assumed to be of inferior quality.

c) Food price inflation: This affects both production planning and the purchase planning of food commodities, as inflation in food prices results in a re-orientation of consumer choices and preferences with a progressive reduction in the consumption of certain products (i.e. meat, fish and other more expensive food items).

### 8.4.3 Non-economic conditions

a) Cultural and social dimensions: Lack of knowledge and skills about food preparation and cooking, owing to gender roles, leads to bad management of food in the current scenario of changing lifestyle where more and more people are living alone or in nuclear families; incompetent planning during cultural practices such as weddings, festivals and other celebrations; decline in the value of food due to rising incomes.

b) Environment and climate: Climate change and human unpreparedness leading to lack of adequate response from governments, farmers and technologists and innovators.

c) Policy: Lack of technical infrastructure for agro meteorological forecasting and market price forecasting, poorly designed subsidies, lack of insurance schemes for farmers and no strategies for risk reduction.

d) Legislation: Lack of globally harmonised quality standards, food safety legislations and food labelling protocols. No information regarding efficient usage of food products and guidelines on decoding food labels (i.e. “best before”, “use by”) and no guidelines on appropriate and ethical disposal of food.

e) Private standards: Aesthetic or functional standards, mainly based on shape, color, size, fullness of the produce, set by producers and retailers.

## 8.5 RELATIONSHIP BETWEEN LEGISLATIONS/POLICIES AND FOOD WASTE

The immediate role of any food legislation is to protect the consumer and their health. But if we observe closely, legislations, regulations designed to ensure safety and quality such as food standards, labelling requirements and food contact material, often contribute to encouragement of wasting food. Owing to varied interpretations depending on the function of the standards and on the specific characteristics of the product a lot of safe and consumable fruits, vegetables and packaged food products go in trash owing to the either the lack of categorization in the standards or the presence of very high threshold values of quality (Segrè, Falasconi, 2011; United Nations Economic Commission for Europe, 2008).

Apart from the extremely aspirational quality standards, another potential cause of food waste is the misunderstood labelling requirement of “best before” and “use by” date for food products. Consumers tend to misinterpret and identify “best before”, “use by”, “sell by”, and “display until” as the same i.e. product not fit for consumption. (European Commission, 2011; Parfitt et al. 2010; WRAP, 2008).

### 8.5.1 Food Legislations that promote food waste

Recently, on 15 June 2015, a report on Review of EU Legislation and Policies with Implications on Food Waste was released. The report was a result of an Impact assessment of EU legislation and policy measures on food waste. The report, with time and resource restrictions of its own, could identify a total of 53 EU legislations which impacted food waste and put them in 5 categories (implying Food Waste Generation, implying Food Waste Management, implying Food Waste Reduction, implying Food Use Optimization, and more than one implication). The findings, although specific to EU, provides us with the starting ground for studies that can be conducted in other countries also. For instance, the legislations put under cluster 1 i.e. Legislation Implying Food Waste Generation, consisted of the regulations and standards touching the following broad areas:

a) **Marketing Standards for Fruits and Vegetables**: These standards include rules defining the shape, size, color of particular fruits and vegetables. The emphasis of these standards is mainly on the aesthetics and not on any potential health hazards, and thus implying wastage of perfectly edible fruits and vegetables if they do not meet the aesthetic standards.

b) **Catch restrictions**: This restriction lays down a Quota/limit of fish species for each EU Member State. Which implies that if the catch exceeds the limit, the extra fish has to be discarded.

c) **Standards for contaminants in food**: These standards fix Maximum Residue Levels (MRLs) for different contaminants in different food categories. In case the contaminant level exceeds the MRL specified the food must be discarded. However, with advancement in technology applied for detecting the levels of contaminants, a zero-tolerance criterion has come into place. This, creates a possibility of avoidable food wastage, wherein the food having “safe for consumption” level of contaminant may also be discarded. More studies establishing the effects of contaminants w.r.t the level pf presence need to be taken up.

d) **Food information**: The legislations relating to providing accurate and reliable information to consumers about the possible expiry of product’s quality and safety are not very clear. While, it empowers consumers to make informed choices, the misunderstood interpretations around “best before,” “use by,” and “sell by” dates lead them to discard perfectly edible food before they expire.

e) **Hygiene rules**: These legislations lay down Good Hygiene Practices applicable to the Food Business operators involved in producing, storing, transporting, packaging etc of food. The guidelines take care that whatever reaches consumer is well within the limits of safe and hygienic levels prescribed and prevents any kind of food borne illnesses. However, some experts are of the view that there might be rules which are excessively binding and/or not applicable across the geographies owing to change in ambient temperatures, storage conditions etc. For example, the number of days where grains, eggs etc can survive w/o any deterioration varies at different storage temperatures and discarding them before they are actually spoilt might be a possibility if the rules say so.

f) **Eco Label**: Eco Label is a kind of reward system to encourage environment friendly practices by the products and services industry. While it may not be encouraging waste generation, but it has huge potential in reducing the same by including “food waste generation “as one of the criteria in the grading matrix.

g) **Private standards**
Beside formal standards, set by laws and regulations, private standards, often set by producers, might be a source of food losses and wastes. More targeted towards fulfilling consumer’s aesthetic demands, private standards tend to focus on perfect shapes and sizes of the farm produce, sometimes processed food products such as breads and bakeries also get discarded sue to some minor visual inconsistency. (high cosmetic food standards) so there is a reciprocal influence between consumers and retailers (Stuart, 2009).

## 8.6 SOLUTIONS: WHAT IS ALREADY BEING DONE?

### 8.6.1 Government decisions addressing food loss and waste

a) In 2017, Australian government, as a part of its Food Rescue Charities Program, has decided to 1.2 billion dollars in achieving the target of reducing the food waste it generates by 50% by 2030.
b) On 23 June 2017, in line with the UN Sustainability Goal 12.3, in Norway, 5 Ministries 12 food industry organizations, agreed on halving its food waste across the food value chain within 2030.
c) In Feb 2016, French government officially banned supermarkets from throwing away food approaching its best before date and encouraged them to donate it to the charities and food banks instead.
d) In 2013, South African government under its National Organic Waste Composition Strategy, targeted to bring down the organic waste (including foodstuffs) to zero.

e) In 2013, the Spanish government launched it More Food Less Waste plan in order to limit the food loss and waste incurred by Spain
f) Italy, in 2014, aiming a 5% reduction per unit of GDP of municipal waste by 2020, released the National Food Waste Prevention Plan
g) In 2016, the United States announced plans to seek a 50% reduction in waste of food by 2030.

More data about government initiatives across the globe can also be sought from a report by Jon Hopkins Bloomberg School of Public Health, which after reviewing 93 identified plans consisting of actionable strategies or targets, from 36 municipals, 18 countries, 20 states, and 19 national governments came out with following interesting observations:

- With more and more governments addressing the issue of food waste in either their Waste Management or Climate Change Plans and overall dramatic increase in such plans is visible from year 2000 onwards.
- Many plans set a numeric target although only few such plans include an evaluation component as well

### 8.6.2 Other Initiatives

a) FAO and Private sector jointly launched the **Global Initiative on Food Loss and Waste Reduction (also known as SAVE FOOD)**, in 2011. It is possibly the largest global initiative to reduce food loss and waste. This initiative takes into account four aspects: 1) Research and Assessment; 2) Support for evidence-based policies; 3) Building awareness (such as "Think.Eat.Save"); and 4) Coordination of global initiatives

b) The European Commission currently co-funds two more global initiatives: one aimed at reducing food waste in Europe **(FUSIONS)** and one aimed at estimating food loss in Africa south of the Sahara **(APHLIS)**.

c) **The Waste & Resources Action Programme (WRAP)** and the **Love Food, Hate Waste** campaign – Britain: WRAP's Love Food, Hate Waste 2007 campaign successfully lead to prevention of 137,000 tons of food going as waste into landfills and instead through its awareness led campaigns utilised it in charity (WRAP, 2007).

d) **This is Rubbish** (www.thisisrubbish.org.uk) is a citizen led initiative, consisting of youngsters in Wales, who work towards raising awareness and seeking shared responsibility from consumers and industries on reducing the food waste. The idea is that all the retailers and FBOs in the area document the amount of foods that could go waste at their outlets and make that information public. Through this initiative, various support events such as **Feeding the 5000, Dining Down to Earth** (a dinner for 100 people), **Hungry for Activism, and Feast Machynlleth** (a communal dinner party made with local surplus) have been organised.

e) **Approved Food** (www.approvedfood.co.uk), it is the primary channel for retailing dry goods and beverages online in Great Britain. This channel advertises products close to “best before “at discounted prices. It also works toward raising awareness amongst people that the actual life of food is much beyond the “best before “date printed on the label.

f) **Last Minute Market** (LMM) a marketplace aiming to recover and sell the unsold goods for charity, is an initiative by the University of Bologna. It is supported by teachers and researchers of the University. With over 40 projects implemented in Italian municipalities, provinces and regions, LMM has developed a working method that activates the donations/pick-up system progressively, checking nutritional, sanitation, logistical, and tax aspects.

g) **The Food Bank Foundation Onlus (FBAO)** 1989, organizes National Food Collection Day and collects the unsold, surplus agri produce from industries, wholesalers, large scale retailers and the likes. This produce is then distributed amongst the charitable organisations, aid programs and those who are needy.

h) **French Environment and Energy Management Agency (ADEME)** is an agency with a primary mission driven towards environment protection. ADEME through one of its campaigns spreads awareness amongst consumers about food waste generation and how it can be prevented, with the view of bringing about a behavioural change in the longer run.

i) **Zu gut für die Tonne** (Too good for the garbage), launched in March 2012, by the Germany’s Federal Ministry of Food, Agriculture and Consumer Protection (BMELV) ia a campagn led initiative which aims to provide consumers with practical advice on managing their food supplies better. It encourages consumers to preserve more and waste less and purchase only as per requirement

j) The German Logistics Association (BVL) also launched an informational campaign on the expiration date of food products.

k) **Food Recovery Challenge**, launched by the U.S. Environmental Protection Agency (EPA) under the Sustainable Materials Management Program is a slightly different format. Instead of only spreading awareness it also challenges participants, which are mainly industries, to minimize their food waste, which in-turn results in them saving money, and also contributes in environmental protection. Companies that join are encouraged to the assess the amount of food waste they generate and then preparing a goal to reduce a certain amount of food waste that ends up in landfills by the end of 3 years.

Numerous other initiatives are being run by national and state governments, development bodies, industrial confederations, local communities, NGOs and educational institutions around the world. But there is a gaping need to and exhaustive list of such initiatives, their analysis and assessment of their impacts. An elaborate study on the effectiveness of such initiatives may help us in streamlining and pinpointing at the most critical factors that need to be considered while quantifying the issue of food loss and food waste and thereafter, its proper, effective solution being built.

### 8.6.3 What more can be done to reduce food waste?

Reducing the amount of food that is lost or wasted is an enormous challenge and calls upon all the sectors alike, to take actions. While the government needs to work on the policies, it is only with the collaboration of private sector and academic and development institutions that full proof, economically and socially viable policies based on concrete analysis of the entire food value chain can be designed.

All the aspects, right from the seeds, soil, climate, meteorological forecasting, market value, transportation, storage, retail, cooking and consumption from the perspective of organized large-scale contract farming to small land holding farmers needs to be taken into account. Consumers on the other hand have an even bigger role to play, by committing to responsible consumption, minimum wastage, and being innovative with preparation and preservation practices of food.

With all that being stated, to summarise a few basic points that can serve as starters for all the sectors in taking the first step towards reduction of food loss and wastage, FAO in its report has suggested the following:

a) developing better food harvest, storage, processing, transport and retailing processes
b) Joining farmers together in cooperatives or professional associations
c) raising awareness amongst producers and consumers alike
d) better monitoring to improve data on the amount of wastage and where it occurs.
e) better communication among all participants in food supply chains
f) reduced, or better, food packaging
g) better consumption habits
h) reconsidering over binding food legislations
i) developing legislation aimed at lowering food wastage
j) redistributing safe surplus food to those in need
k) incineration of food waste with the energy released being recovered.

## 8.7 CONCLUSIONS

As is visible, enough data on the amount of food either lost or going waste has been collected. The real challenge now is to structure that data in a way that it gives us more insight into patterns of food supply chain, and pin points on the areas that policy, science and technology collectively need to work on, in order to reduce the wastage on one hand and ensuring food security for all on the other. There is an immediate need to focus on utilising the existing data and resources in designing perceptive, feasible and innovative solutions to minimise this needless wastage of food.

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# Food Security: Impact of Climate Change and Technology

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