Ensuring water and food security in a developing Sub-Saharan Africa

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Introduction

The human population is expanding faster than ever. The world population has more than tripled over the last century and today more than seven billion people share this planet. However, the increase has not been homogeneous across the globe, and the main population growth is found in the developing countries (United Nations 2008). Now, more than 80 % of the world's population live in countries where income differentials are widening. As of 2005 approximately 50 % of the world's population lived below the poverty limit (below US$ 2,15) (The world Bank 2012), and 1.4 billion people, or one quarter of the population of the developing world, lived in extreme economical poverty (below US$1.25 a day in 2005 prices) (Chen and Ravallion 2008). During the last 30 years the ecomomical progress of the world has been uneven across regions. In Asia the poverty rate fell from 80 % to below 20 % while it stayed at around 50 % in Sub-Saharan Africa (Chen and Ravallion 2008). In Africa, Sub-Saharan countries have been forced by their external debt to undertake economic adjustments while devoting foreign exchange to pay off debt. The World Bank (1998) has classified 38 countries as 'severely indebted low-income countries', of those 29 were found in Sub-Saharan Africa (Boyce and Ndikumana 2001). The world is changing. Urbanization is a booming trend, especially in Asia and Africa. More and more people move to the urban areas, and today more than 80 % of the world population live in such areas (WHO 2012). Urbanization leaves more people to be fed and less to produce the food required – a trend that has put further pressure on food prices, food production, agricultural methods and overall food security.

Since the 1960's the world food security has significantly increased. Nevertheless, 20-40 % of the children in Sub-Saharan Africa still suffer from malnutrition, high mortality rates, and limited access to clean drinking water (Sen 1999). Climate changes, prolonged drought and uneven rain patterns have showed the importance of conserving every drop of water. Along with urbanization, population growth and a warming climate, water consumption is predicted to increase in the future, hereby putting more pressure on this vital recourse. Food production is water costly and more than 90 % of the total freshwater resources are used for irrigation in arid areas like Sub-Saharan Africa (Shiklomanov 1999). Whatever the use of freshwater (agriculture, industry, domestic use), a huge saving of water and improved water management is a necessity in order to ensure adequate water resources for the future. Rainfall patterns and water availability for irrigation is correlated to the economical welfare of Sub-Saharan countries. In Ethiopia the amount of rainfall is correlated with the GDP (Gross Domestic Product) and reduced water availability might cause increased economical crises (Fig. 1) (The World Bank 2007).

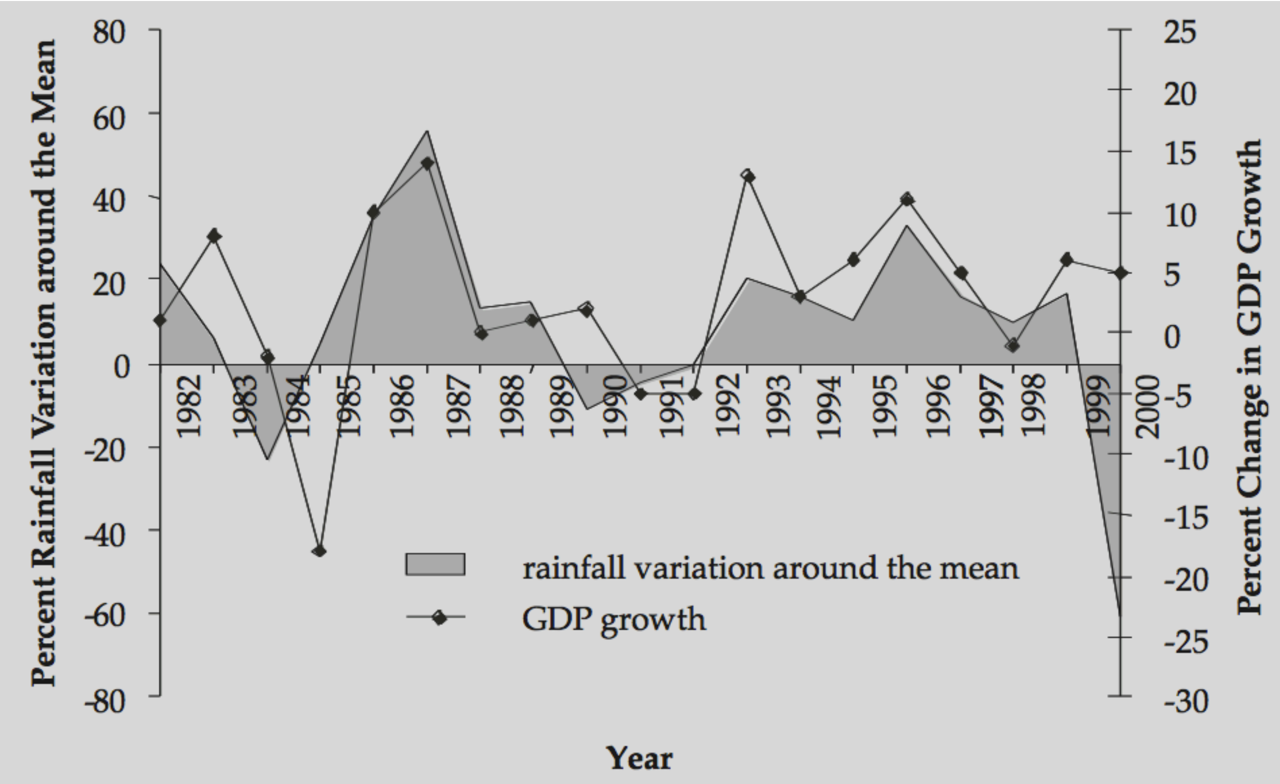

Figure 1. Rainfall variation and GDP growth in Ethiopia (The World Bank 2007)

It has long been recognized that the lack of adequate food supply and poor nutritional status of populations in developing countries is one of the major problems in economic and social growth. Consequently, large amounts of granted development aid have expended considerable effort in the fields of agriculture and nutrition (i.e., the development aid for area of "food production and nutrition" contributed 55 % of total development assistance (US alone) from 1975 through 1985) (Herdt 2010). Mainly, the aim has been to increase agricultural production, restore soil fecundity, and efficiency while also decreasing field losses (like in Tigray, Ethiopia) (Edwards et al. 2010).

However, increased agricultural production is not enough to improve and ensure proper food security in developing countries. Broader changes including food habits, agricultural methods, and improved food transportation are all vital, if one is to develop a sustainable water use and secure food for future generations in the Sub-Saharan Africa. The increased food production must pass safely along the chain that links farmer and consumer (termed the Food Pipeline after Bourne (1977)). Today, large amounts of food are shipped without ever reaching the consumer. The Food Pipeline as an important link in the process of ensuring adequate food supplies, has often been overlooked in the literature and developing aid (Bourne 1977). Postharvest transport is associated with losses of food (e.g. vegetables, fruits, and meat) before it reaches the consumer. Postharvest handling and transport are of increasing importance as urbanization and a globalization have changed the world market. Food is readily transported 10000 of miles by car, train, boat and flights from Africa to the stores around the world. New estimates puts postharvest losses of fruit and vegetables to reach very high values, representing more than 25 % of the total production in industrialized countries and more than 50 % in developing countries during transportation from producer to consumer (Fig. 2) (Kader 2005; Nunes 2012). To minimize loss various techniques have been developed and applied during transportation. However, the methods traditionally used have disadvantages and weaknesses. *Chemicals and pesticides* have been widely applied, but now due to environmental concerns and health risks, more countries have banned those agents (Adaskaveg and Förster 2010). Today, with an increased use of agro-ecological farming methods, demand of sustainable sources, and organic products more consideration is paid to naturally derived compounds or natural products as a mean of reducing postharvest losses. One novel, ecological and sustainable technique known as *Biologial control,* or *biocontrol* is now quickly expanding in the postharvest handling process. The method is already widely used in farming practices around the world (Hajek 2007), but has so fare often been overlooked in other perspectives of the food handling process (Wilson and Wisniewski 1989).

This report focuses on elucidating the importance of postharvest handling of food production. It outlines the nature of the problems associated with post harvest food losses, the causes of losses, and describes the most common methods used today to reduce postharvest loss, and the potential of biological control. The main aim of this report is to explain to what extent losses due to biological reasons may be prevented by the use of biological control, and how this organic approach promise for increasing the available food and water supply in developing countries.

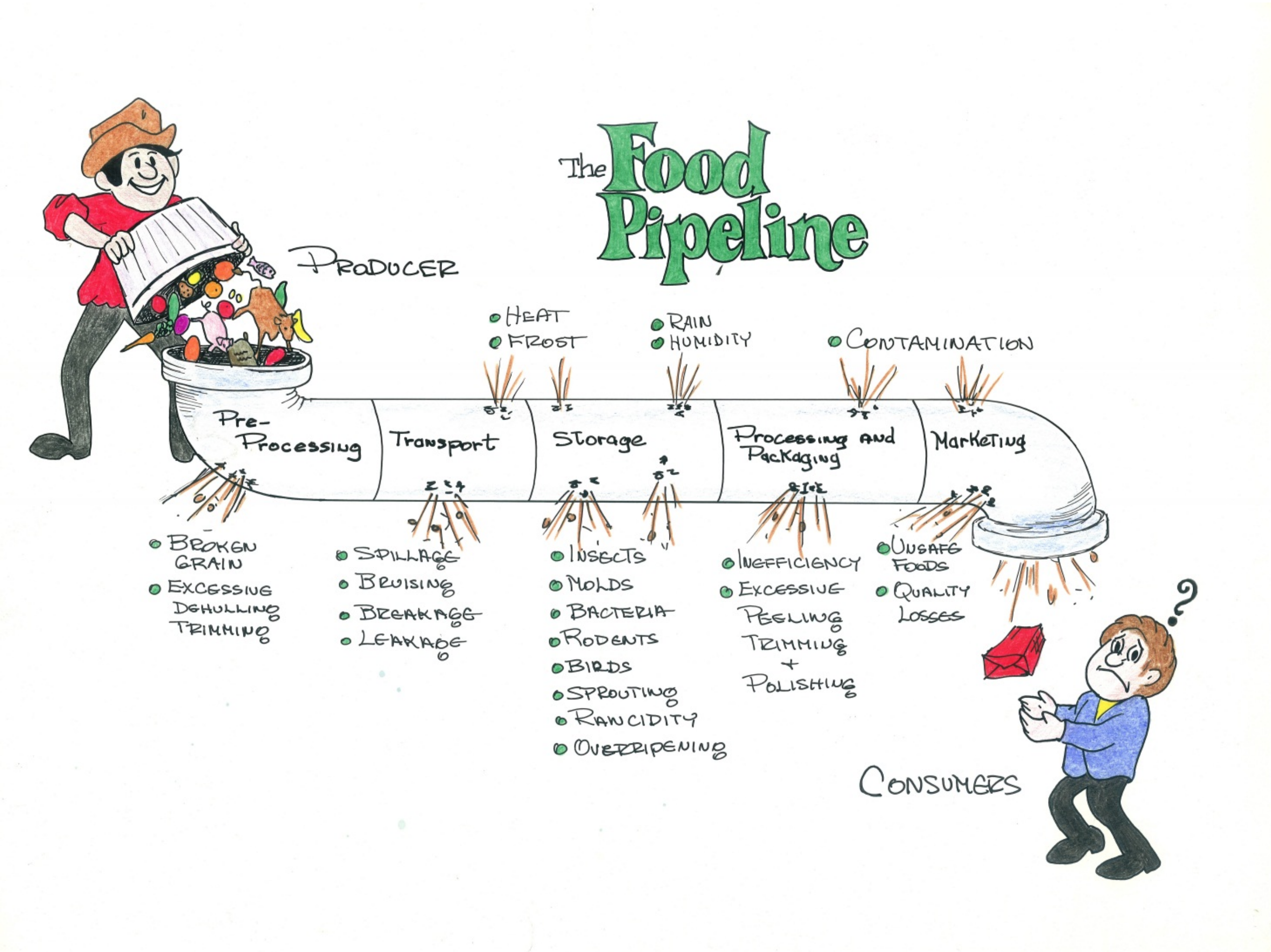

Figure 2. The Food Pipeline. Illustration of the stages and potential food losses during postharvest handling from producer to consumer (Bourne 1977).

Problems of losses in postharvest processes

Time, money, water and energy are all required to produce food products, and unless the farmer is exclusively producing for own use, he automatically becomes a part of the global, regional or local market. Simply, he has to sell his produce, he must recover his costs, and he must make a profit in order to survive. The transportation of food was termed the Food Pipeline by Bourne in 1977, and is today widely adapted. Factors as production losses, consumption potential, and market stability in developing countries are difficult to quantify. However, estimates of the postharvest losses of crops (e.g., fruits and vegetables) in the Food Pipeline was found to vary between 25 % to 50 % in certain areas of the developing countries due to *mishandling, spoilage and pest infestation.* 40 million tons of fruits and vegetables (amounting US$ 13 billion) are annually wasted in India alone. Globally this translates into that somewhat between one-quarter and a third of what is produced never reaches the consumer (Burden and Wills 1989; Kader 2005). The loss is a waste of money, effort, and water required to produce the lost products. Fruit, vegetables and root crops are sensitive to handling, and are likely to perish too soon if proper care is not taken during harvesting, handling and transport (Pérez et al. 1999). Crops like sweet potatoes, plantain, tomatoes, and citrus fruit are all highly sensitive - more than 50 % of the harvested is often lost (Burden and Wills 1989). Reduction in this wastage would be of great significance to growers and consumers alike. Postharvest handling, storage, physical and biological conditions are important to reduce perishing.

Causes of losses

There are three primary causes to food degradation during transport: (1) *Biological and microbiological infections,* as food is attacked, infected or damaged by microbes, fungus, insects, mites, rodents, birds etc. (2) *Chemical* reactions between chemical compounds in the food (e.g., fat oxidation, enzyme reactions, contamination of pesticides) (Bourne 1977). (3) *Mechanical* or *physical* damage to the products including wounds, bruises, puncturing, and sub-optimal environmental conditions (e.g., cold, heat, humidity).

Biological pathogens

During transportation fruits and vegetables are lost due to the attack of several pathogens (e.g., fungi, bacteria) because of high amounts of nutrients, water or low pH values (Pérez et al. 1999; Kader 2005). Furthermore, harvested fruits intrinsic resistance to protect themselves against natural pathogens is decreased, compared to hanging fruits (Droby et al. 2002). As of biological deterioration a wide range of causes has been described including: respiration, ethylene (production and action), humidity, water stress, sprouting, rooting and rates of compositional fluctuations (e.g., color, texture), mechanical injuries (wounds), physiological disorders, and pathological breakdown. Additionally, the rate of which deterioration occurs depends on several external factors (e.g., temperature, air velocity, sanitation, carbon dioxide, and ethylene content in the air) (see Bourne 1977; FAO 1981; Burden and Wills 1989; Janisiewicz and Korsten 2002 and references within)

Postharvest handling methods

Different methods are used in the postharvest process in order to ensure the quality of the products. Here I will present two of the most commonly applied techniques used today.

The cold chain

In contrast to pathogens attacking hanging fruits, most of the postharvest pathogens are incapable of penetrating the fruit surface. They often require a wound in order to penetrate and handling-carefulness is therefore important to minimize physical damage on the food. The content of mycotoxins, toxic stress metabolites, or simply rot created by microorganisms in food products has been found to be a major dietary problem in developing countries (Eckert and Ogawa 1988; Wilson and Wisniewski 1989). The development of microbes (virus, bacteria, and fungus) is effectively suppressed by ensuring constant low temperatures during transport. Temperature regulation has received much attention, and failure to "maintaining the cold chain" directly from harvest to consumers has often been proposed as the main reason of pathogen attacked fruit (Likar and Jevšnik 2006; Rediers et al. 2009). However, not all fruits will tolerant near freezing temperatures, and the low temperature approach has been shown most effective for crops like apples, grapes, and carrots while less effective on certain other crops (e.g., squash, tomatoes) suffering freeze damage if stored below 12 degrees Celsius (Eckert and Ogawa 1988).

Chemicals

Consequently, to achieve a satisfying physiological lifespan during transport, the use of chemicals (e.g., waxes, antimicrobial, and antifungal agents) has been introduced. While, antifungal agents have been used as the primary controlling mean, antimicrobial agents have only been used to a more limited extend, and most often in cases where antifungal treatments were found inadequate (Eckert and Ogawa 1985). However, the use of postharvest antifungal chemical use has been increasingly limited following growing concerns about the safety of synthetic chemicals in food products (Adaskaveg and Förster 2010). In addition, the use of fungal chemicals has many disadvantages – e.g. the development of resistant strains of plant pathogens against currently used antifungal agents and higher costs involved with synthetic antifungal compounds (De Costa and Gunawardhana 2012). Today, more European countries have decided that the environmental and toxicological risk is too high and have banned the use of antifungal agents (Adaskaveg and Förster 2010). Moreover the increased demand of sustainable and organic production has resulted in more consideration to be paid to naturally derived compounds or natural products as fungal control agents. Now the available and possible solutions of non-fungicidal approaches to minimize food loss are many. Among the most applied is the use of soft chemicals, natural chemicals, disinfectants, calcium applications, growth regulators, chemical elicitors to induce natural host defenses, biological control agents, hypobaric pressure, irradiation, hot water, modified atmosphere storage, special packaging and genetic manipulation (Barkai-Golan 2001; Janisiewicz and Korsten 2002; Korsten 2006), although some with limited success.

Biological control

Biological control has many advantages: Is it a safe and sustainable method that may be applied directly to the infection site and is highly capable of managing and controlling postharvest diseases in food if used properly. Conversely, the development process of biological controls agents is long, costly, and complicated (Nunes 2012). This process consists of two overall components: *discovery* and *development* (Fig. 3), before it is ready to be applied. Development of new biological methods are not easy, and many criteria has to be fulfilled for it to be successful (e.g., stable, inexpensive, resistant to pesticides, non-toxic for humans, and effective in small concentrations) (Wilson and Wisniewski 1989). Figure 3 is a simplified illustration of the involved factors in the complex development of biological control.

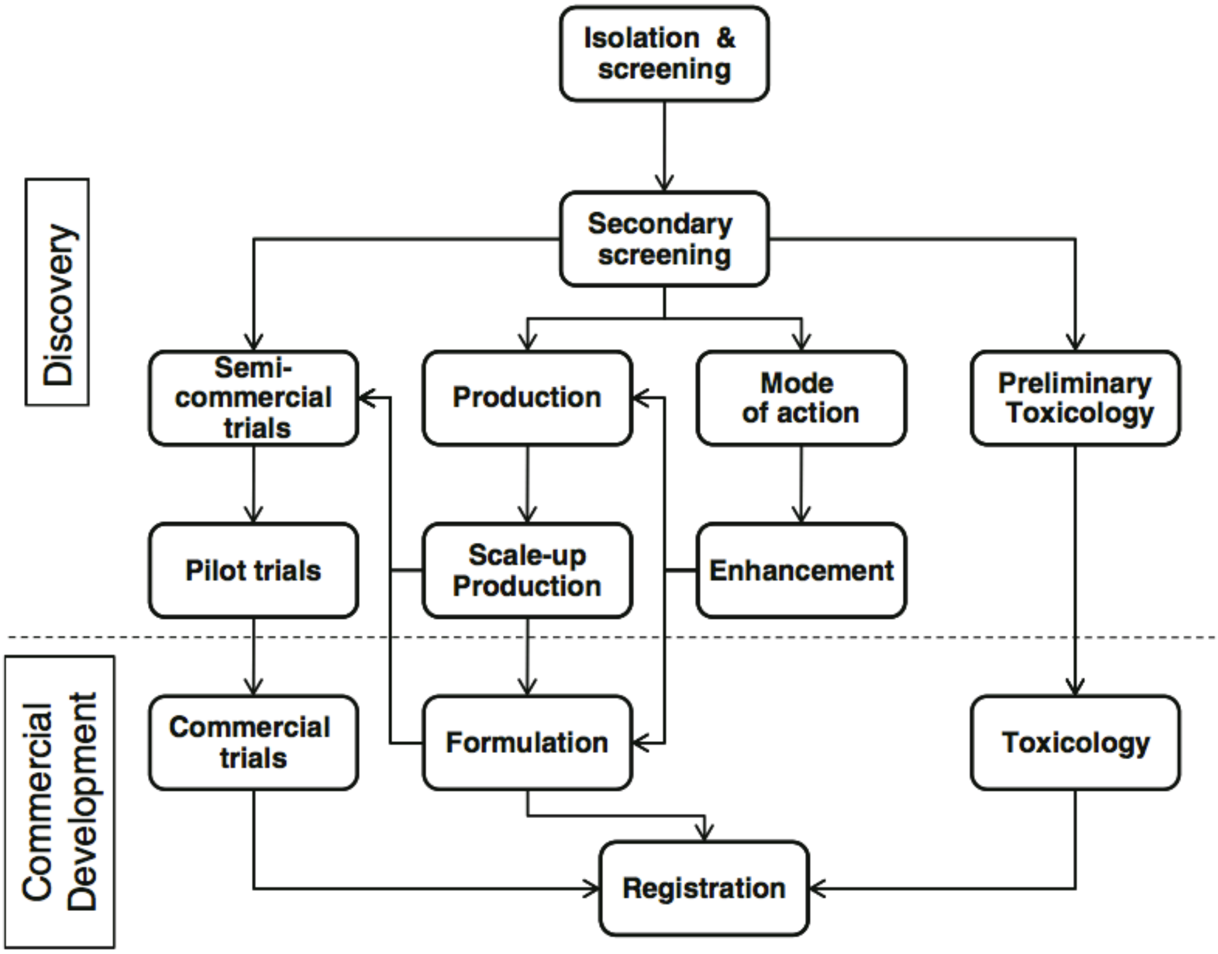

Figure 3. Diagram of development of a postharvest biological control agent (Nunes 2012).

Mechanisms of biological control

Biological control agent's work is known to vary among species. Here some of the mechanisms used in biological control are presented (Also see figure 4 for species examples):

Competition

The biological control agent (antagonist) successfully outcompetes the pathogen in the competition of nutrients or space. Antagonists using this approach have to be carefully selected, as they have to be better adapted to adverse environmental conditions compared to the pathogen. Many pathways are possible: The antagonist exhibits a rapid growth rate, it utilizes nutrients effectively (even at low concentrations), it survives and develops on the surface of the fruit or directly at the infection site. The antagonist may be helped along by creating conditions (e.g., temperature, pH, humidity), which are negative for the growth of the pathogen. However, such antagonist will only inhibit, not destroy it (Wilson and Pusey 1985; Wilson and Wisniewski 1989).

Antimicrobial substances

Antibiotic production has been suggested as responsible of biological control activities of some bacterial and fungal antagonists. The applied biological control agent attacks the pathogen directly by producing antibiotics. This is not uncommon in nature. It is an important mechanism, found in some species as protection against diseases. The controlling activity is mainly due to the production of antifungal compounds (e.g., antibiotics, predominantly lipopeptides of surfactin) (Stein et al. 2005). The potential microbial control of postharvest diseases of citrus fruit was first reported in 1953, by using the bacteria *Bacillus subtilis*. This microorganism has been reported as antagonistic of postharvest diseases of fruits (Wilson et al. 1991). It may be debated whether an antibiotic-producing microorganism should be used in the sense of postharvest biological control, due to the concern of introducing an antibiotic into food and development of a pathogen resistance. However, this discussion it not in the scope of this report, but should be debated elsewhere.

Crop	Disease	Antagonist	
I. *Antibiotic Production*			
Apple	Blue mold	*Pseudomonas cepacia*	
"	Mucor rot	"	
Apricot	Brown rot	*Bacillus subtilis*	
Cherry	"	"	
"	Alternaria	*Enterobacter aerogenes*	
Citrus	S. E. rot	*B. subtilis*	
"	Sour rot	"	
"	Green mold	"	
"	Sour rot	*Trichoderma* sp.	
Nectarine	Brown rot	*B. subtilis*	
Peach	"	"	
Pear	Blue mold	*P. cepacia*	
"	Gray mold	"	
Plum	Brown rot	*B. subtilis*	
II. *Nutritional Competition (N) and/or Induction of Host Resistance*			
Apple	Blue mold	*P. syringae*	(HR)
"	Gray mold	*Acremonium breve*	"
"	"	*Debaryomyces hansenii*	(N+HR)
Citrus	Green mold	"	"
"	Blue mold	"	"
"	Sour rot	"	"
Grapes	Gray mold	"	(N)
"	Rhizopus	"	"
Peach	"	*E. cloacae*	"
Tomato	"	*D. hansenii*	"
"	Gray mold	"	"
"	Alternaria	"	"

Figure 4. Biological control of postharvest diseases of fruits. Suggested methods of actions (Wilson 1989).

Parasitism

The attachment of microorganisms to the pathogen has been described as an important factor in biological control (Arras et al. 1998). It is possible that the attachment of the antagonist to the pathogen facilitates a more efficient depletion of nutrients or it may serve as a mechanical barrier to nutrient uptake by the pathogen. The knowledge of parasitism as a biological controlling mean is, however, still limited (Droby et al. 2002).

A case study of biological control agents

Antagonistic yeasts have been selected mainly for their proficiency of rapid growth and competitive abilities in surface wounds. As yeast occur naturally on fruits, vegetables and crops it has been targeted by many researchers as potential biological control agent of postharvest diseases because they exhibit a number of traits that enhance their potential for colonizing fruit surfaces (Droby et al. 1998). A series of studies carried out by Droby and colleagues (1998) and the success of these antagonists in laboratory experiments, and other large-scale studies have caused a growing interest in the development and use of yeast as biological control against postharvest rots of fruits and vegetables. Their studies, on four yeasts as an antagonistic microorganism applied on grapes showed a significant reduction in grape decay compared to controls (Fig. 5b). However, a large variation was found in the efficiency of the antagonist, and is it therefore important to apply the right organisms/antagonists in order to gain the largest effect. In this particular study *Candida olephila* found to be the most effective antagonist reducing the fruit loss of grapes by approximately 65 %. *C. olephila* works efficiently on the pathogen *Penicillium digitatum,* and effects of applying *C. oleophila* cell onto the grapefruit surface increased their resistance and the decay rate was decreased with 61 % during 24 hours (Fig. 5a).

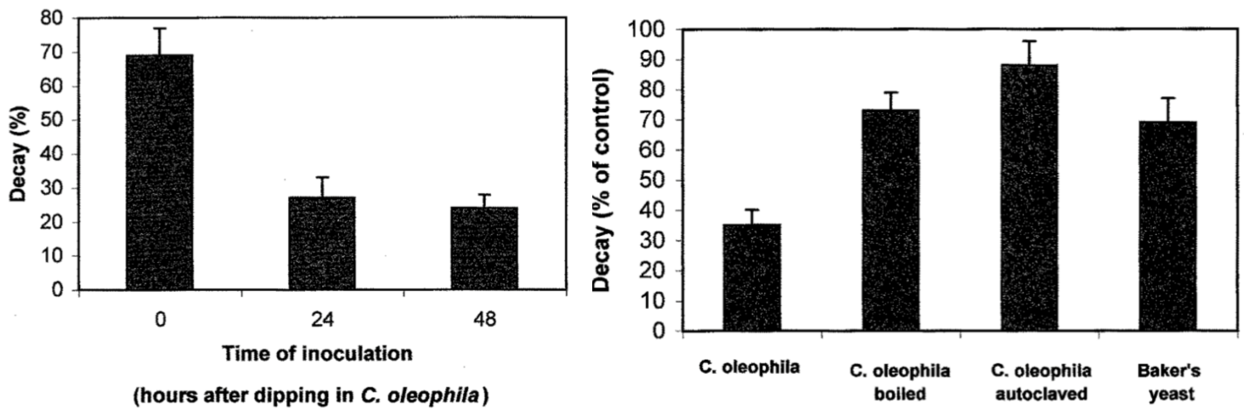

Figure 5. a) Reduction of decay found on intact grapefruits dipped in a solution of *C. oleophila* after 24 and 48 hours. b) Effects of four different yeasts as a biological control against *Penicillium digitatum* attack on grapefruits measured as % decay of control (Droby et al. 1998).

Although, the biological control activity of antagonistic bacteria and yeasts has been demonstrated on a variety of food products, the mode of action of these microbial agents has not been fully explained. The complex interactions between antagonist and pathogen was simplified by Wilson and coworkers (1989) and illustrated in figure 6. Antagonist, pathogen, and infection site is also affected by the resistance residues in the fruits, and the potential interactions of other microorganisms (not targeted by the antagonist) may influence the effectiveness of the used biological control agent (Wilson and Wisniewski 1989).

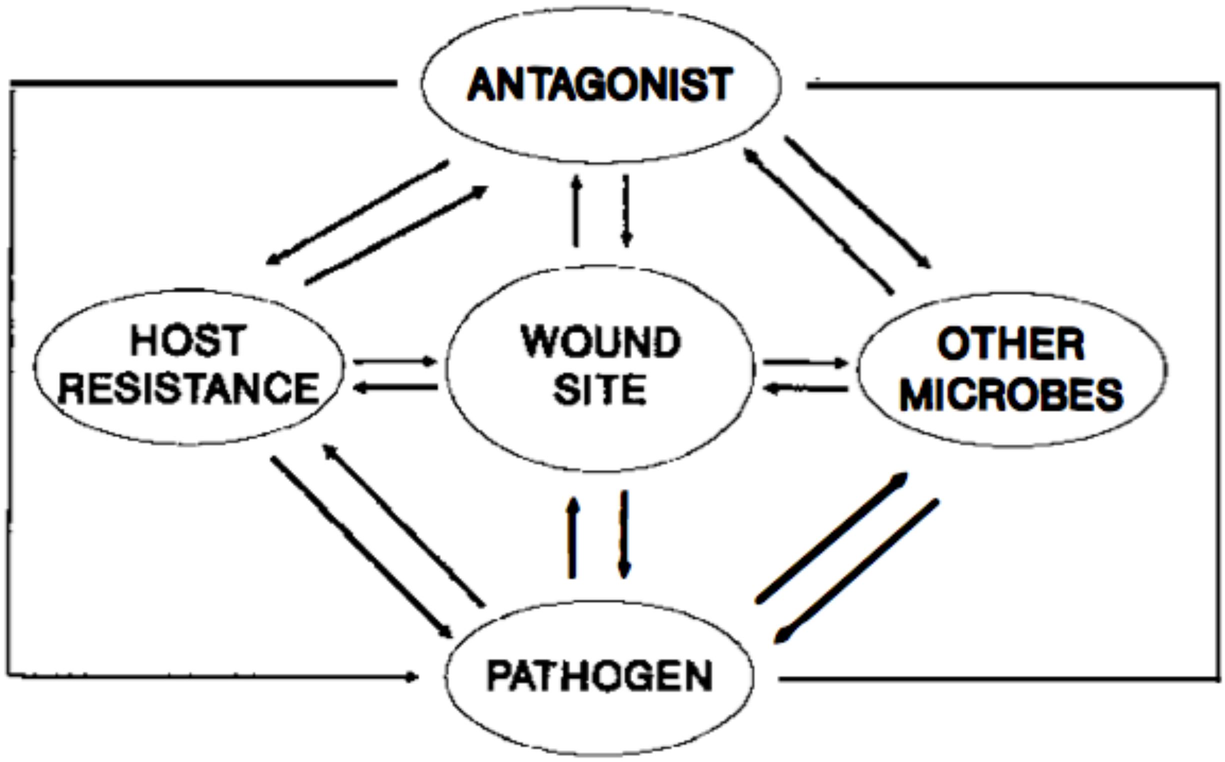

Figure 6. Interactions between the host, Antagonist, and pathogen (Wilson 1989).

Conclusion and future potential of biological control

Biological control provides high potential for future management of postharvest diseases, because of its non-toxicity to humans and the environment. However, this type of control has showed reduced efficiency, especially when pathogen cell density is high or it is used against pre-existing infections (Hong et al. 1998; Eshel et al. 2009). Biological controls used against fungicides have received the highest degree of attention in the literature. Biological antifungal products (e.g., US-7, *Trichoderma, Bacillus sp.*) is already well establish on the market (Wilson and Wisniewski 1989), and will probably become even more applied in the future. Microbial ecology principles will be important in any future effort to practice ecological sustainable pest management. The lack of understanding the important interactions and mechanisms in the antagonistic-pathogen relationship in relation to control of pests and other microorganisms is still high. This missing knowledge limits our ability to understand the processes that occur during our efforts to implement more ecological methods (Gohel et al. 2006). It is unrealistic to assume that perfect growth, and living conditions always will prevail for the antagonist in the process and during transport. Therefore, biological control agents will rarely be the only measure of disease control, but more likely used in combination with other methods. Results from an experiment on carrots and Black Root Rot by Eshel and coworkers in 2009 revealed highly beneficial results when physical, biological and chemical antifungal residues were combined. As it is possible to make species-specific combinations biological control should be viewed as an important component in reducing the food loss in the Food Pipeline in a sustainable ecological way.

Biological control agents have the potential to significantly reduce the amount of food lost in the postharvest process every year. However, in order to enroll biological control in the postharvest process more education is of central importance. The significance of postharvest food losses is known in developed countries but not in developing countries. Therefore, a large-scaled educational plan is needed. Education including information, methods and knowledge is needed across all societies in the developing countries, in order to obtain significant results. Education should awaken the population's awareness to the extent of postharvest losses, and how this loss can be reduced efficiently. Many areas in the Sub-Saharan Africa have certain traditions and it is a big challenge to educate the entire developing world. Education should cope with superstition and disbelieve, as it may be difficult to believe that microbes under controlled conditions may help preserve food. The populations of developing countries should ideally understand that stored food is a living biological system that must be protected in order to maintain its quality during long transportation. However, new projects (e.g. The Tigray Project (Edwards 2010)) aimed on improving farming practices in local communities by means of sustainable ecological agriculture are promising. These projects work at community scale. Other projects educate the farmers on there terms by well planned "Farmer Field Schools" and "Farmer Family Learning Groups". Integrating knowledge of postharvest food loss and the biological approaches could beneficially be included in such projects.

All studies reviewed writing this report revealed how the use of biological control reduced the food decay. Some with decay reduction of approximately 60 % when optimal biological control agents were used (Droby et al. 2002). This increased success will have tremendous implications for the Sub-Saharan countries on a national and local scale. Consumers in this region spend more than 60 % of household income on food. The increased food availability facilitates food security and may prevent food prices rising further. Moreover, the implicated farmers will experience an increased income, as fewer products are destroyed (The world Bank 2011).

Grain production in Sub-Saharan countries is estimated to an annual value of US$27 billon (2007) and the loss in the postharvest process is estimated to be billions of dollars (The world Bank 2011). Even a small reduction in postharvest loss by the use of the organic approach *biological* *control* may therefore be of significant importance to the development in those countries' economy. A reduced loss is likely to enhance food security through improved farm-level productivity benefiting producers and the rural poor. The cost of implementing, discovering, developing, and the approval work of biological control agents need to be taken into account (The world Bank 2011). However, promoting food security through reduction in the postharvest process may likely be more cost-effective and environmentally sustainable than an analogous increase in production, especially in a changing climate, a period of high food prices, and a global economical depression (The world Bank 2011). Even the very conservative estimate that biological control only reduces the loss of grain by 1 %, annual gains of US$40 million (2007 prices) are realized, with the farmers as the central beneficiary (The world Bank 2011). If biological control can reduce the loss by 15 % of the produced, this equals the annual value of cereal imports of Sub-Saharan Africa (varies between US$ 3-7 billion annually). This would make the region become further independent and the amount of food saved equals the food security of more than 40 million people (at 2,500 kcal per person per day).

The piped water system in Sub-Saharan Africa has the smallest coverage in the world and more than 300 million people are without safe drinking water. Provision of water is one of the biggest problems in modern Sub-Saharan Africa and every drop counts (UNEP 2010). As more than 90 % of the total freshwater is used for irrigation, a reduced food loss followed by the use of biological control, would mean less water needed to be spend on failed crop production, and hereby increased amounts of potentially drinking safe water. But, in order to provide water security to the entire population of Sub-Saharan Africa additional changes have to be done. UNEP (United Nations Environment Programme) has already developed a comprehensive guideline towards a more water secure Africa. However, as biological control is a central part of reducing water waste, it is important in securing water and food for the future.

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