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ENVIRONMENTAL CONCERNS OF GENETICALLY MODIFIED ORGANISMS IN FOOD PRODUCTION: IMPLICATIONS FOR AFRICA'S SUSTAINABLE DEVELOPMENT POLICY.

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ABSTRACT

A lot of concerns have been raised on the adoption of Genetically Modified Organisms (GMOs) especially when relating to health, environmental and possible socio-economic effects. However, environmental risk assessments have not been thoroughly considered as a potential aid to regulatory decision making, especially in Africa. Factoring in environmental protection concerns in deciding adoption of GMOs in agriculture can assist in shaping sustainable development policy in Africa. The study relies on scientific literature on environmental costs and benefits associated with the introduction of GMO technologies in agriculture to draw implications for Africa's sustainable development policy. The study concludes that introduction of GMO technology in Africa's agriculture is more likely to cause harm than good to the environment mainly because of the probable risks to the ecosystem. Sustainable development policy in Africa should seriously consider the potential harm to the natural ecosystem together with other socioeconomic and human health effects associated with the technology.

Key words: Genetically Modified Organisms (Gmos), Agriculture, Ecosystem, Sustainable Development Policy, Ethics, Africa

INTRODUCTION

Adoption and use of genetically modified technologies in food production (agriculture) has been intensely, yet controversially, discussed in literature. Application of this technology in food production (agriculture) has been one area heavily criticized (Wickson, 2014). By definition, a genetically modified organism (GMO) is one whose genetic characteristics have been modified by insertion of an altered organism gene of the same species or a gene from other organisms using genetic engineering (Von Wartburg & Liew, 1999). When the gene is taken from the same species it is called intragenic modification whilst when taken from a different organism it is named transgenic modification. The major criticisms of genetic engineering in food production have been in the areas of potential human health effects, environmental and other possible socioeconomic effects (Maghari & Ardekani, 2011; Isa & Man, 2014). An important aspect of the controversy is the potential effects of the technology on the ecosystem. Application of genetic technology in agriculture can have negative and positive impacts on the natural environment's flora, fauna, soils etc., (Hails, 2000; Clark & Lehmann, 2001) which are the components of ecosystems. One of the arguments raised in favor of genetically modified crop technology in agriculture is that the technology might be more suitable to control some problematic species of pests when compared to conventional ways resulting in less pollution from pesticide toxins (Cowgill et al., 2004). Use of genetically modified herbicide resistant crop species may enhance agricultural biodiversity (Hails, 2002). In addition, genetically modified crop species may require less pesticide use hence reducing greenhouse gas emissions from agriculture (Brookes & Barfoot, 2005). Moreover, some scientists believe that water pollution problems can lessen with adoption of genetically modified food crops due to less eutrophication (Weaver & Morris, 2005).

However, scientific arguments have also been raised against the application of GMO technologies in food production. Arguments against genetically modified crops include concerns that herbicide and pest resistant genetically modified crops might lead to an increase in herbicide application (Watkinson et al., 2000; Firbank & Forcella, 2000), and that toxins produced may enter and disturb the food web and thus affecting non-targeted organisms (Marvier, 2002; Harwood et al., 2005). The potential risk on the food web is most likely to have huge impacts on animal species, ecosystems and humans mostly because these effects may be irreversible (Pilson & Prendville, 2004). Another firm argument against the technology is that transgenes (transgenic modification) might escape into the wild populations and transform the natural ecosystem (Pilson & Prendville, 2004; Marvier & Van Acker, 2005). In addition, transfer of transgenic DNA has been highly criticized and has been regarded as an infringement of the integrity or dignity of plants and an interference with the natural order of nature (Balzer et al., 2000; Deane-Drummond, 2004; Verhoog et al., 2003; Sandler, 2007).

The objective of this paper was to perform a comprehensive review of literature on the environmental concerns raised on genetically modified crops in agriculture with the aim of drawing implications for clean technology adoption policy in African agriculture. Several review articles have summed up and discussed different moral concerns on the debate on genetically modified crops (see Robbinson, 1999; Shelton et al., 2002; Weaver & Morris, 2005; Snell et al., 2012;

Bawa & Anilakumar, 2013). However, none of the studies so far have focused on the application of critics of genetically modified crops to policy decisions around smart agricultural practices in developing country agriculture especially in Africa. A closer review targeted towards the identified gap in literature was based on a comparison of genetically modified crops and organic crops (see Azadi & Ho, 2010). However, much emphasis was on food security rather than on environmental protection. This study therefore performed a comprehensive review of literature on the ecological impacts (positive and negative) of genetically modified crops and draw implications for sustainable development policy. Concern is given to policies meant to promote smart and sustainable agricultural technologies/practices in Africa.

This paper extracted the main critiques from the review to discuss the possible implications for sustainable development policies in Africa, precisely how the critiques can be used in decision making when drafting sustainable development policies. This is a very critical step in improving awareness on the potential risks and benefits of GMO technologies in agriculture. Awareness can improve weight of consideration of environmental concerns in drafting future policies for a sustainable development in Africa. A number of developed countries have rejected genetically modified crops based on their potential risks to the environment (Sustainable Pulse, 2015). Official statistics reveal that about 38 countries (mostly developed) have banned genetically modified crops and only 25 countries are currently growing them (Sustainable pulse, 2015). The numbers of countries in the developed world that have banned genetically modified organisms continue to increase and the main reasons being the desire to keep a clean and green image in agriculture. This therefore implies that developing countries in Africa which have already adopted and those which are yet to adopt the technology can also strongly factor in environmental concerns in policy decisions aimed at achieving sustainability.

A lot of emphasis has in the past been given to health concerns of genetically modified crops (Uzogara, 2000; Verma et al., 2011; Isa & Man, 2014). However, environmental concerns are equally critical and need due consideration as well (Brookes & Barefoot, 2013). Environmental concerns are even much important considering the heavy reliance of poor countries on ecosystem services for a living (Suich et al., 2015). History of genetic engineering and its application in food production is important for insight on GMO issues. The next section gives a brief history of application of GMO technology in food production mainly in the developed world.

HISTORY OF GENETIC ENGINEERING IN FOOD PRODUCTION

A research article by Uzogara (2000) provides a comprehensive history of genetic engineering in food production. Genetic engineering in the food industry has been practiced since ancient times. It is said to have been practiced by resourceful farmers by breeding plants and animals to emphasize on certain desirable attributes. This was achieved by gathering and planting the seeds of fatter grains, selecting meatier and hardier animals for breeding, and also by cross-fertilizing different species of plants to create new varieties that exhibit the most desirable traits or characteristics of the parent plants or animals (Schardt, 1994). According to Philips (1994), direct application of genetic engineering techniques started in the 1960s, has continued in the 1990s, and will probably proceed through the 21st century. It therefore implies that the technique has over fifty years in practice.

Genetically modified foods first appeared in the food market in the 1960s (Uzogara, 2000). In 1967, a new potato variety named *Lenape Potato* was bred for its high solids which made it appropriate for making potato chips. Two years later, the *Lenape potato* developed a toxin called solanine and it was withdrawn from the market by the United States Department of Agriculture (USDA) (Uzogar,a 2000). The development of toxin in the *Lenape potato* variety showed an important lesson that genetic engineering in plants and animals can have unexpected effects (McMillan & Thompson, 1979). In 1979, at Cornell University, New York, scientist conducted the first study on recombinant bovine somatotrophin (rBST), a synthetic growth hormone for cows. This hormone was said to increase milk production capacity, when injected into the cow. In addition, in the 1980s, researchers in West Germany (Max Plank Institute for plant breeding), Belgium and the United States (Monsato Corporation) found a method of creating transgenic plants by using a pathogenic bacterium called *Agrobacterium tumefaciens* (Fraley et al., 1983; Zambrynsky et al., 1983). This bacterium was used by the researchers to introduce new genes into plants and also in introducing marker genes for kanamycin resistance to select transformed cells (Bevan et al., 1983; Herrera-Estrella et al., 1983). According to Hinchee et al. (1988) this technique became useful and was used to introduce dozens of other traits into plants including the slow ripening characteristics of tomato. From 1983 to 1989, a lot of more sophisticated recombinant DNA techniques that allowed for genetic transformation of plants and animals were developed. The United States government approved the use of rBST in dairy cows during this period. In the same period the US government provided a framework for regulating biotechnology to three departments namely the Food and Drug Administration (FDA), the US Department of Agriculture (USDA), and the Environmental Protection Agency (EPA) (Phillips, 1994).

In the 1990s, the first genetically engineered foods were made available on the market. An example is that of rennet, used in making cheese, which was approved though it did not receive much attention from the public. The National Institute of Health (NIH) and the American Medical Association (AMA) independently concluded that milk and meat from cows treated with rBST were as safe as untreated ones and a year later, the American Pediatric Association approved rBST. The FDA also approved rBST in dairy cows in 1993. Researchers at Cornell University also produced rPST (recombinant porcine somatotropin) which was to be used in pigs to produce lean pork. The rPST led to reduced feed intake but more meat production, when injected in pigs. In 1994, the FDA gave approval for Calgene Corporation's Flavr Savr Tomato, the first genetically engineered whole food approved for the market (Thayer, 1994). In Scotland, cloning of farm animals from fetal and embryonic cells (Dyer, 1996), and from adult mammalian cells (Wilmut et al., 1997) began. The introduction of terminator seeds (Koch, 1998), the use of the gene gun or biolistic gun technique (as an alternative to the agrobacterium) to shoot foreign genes directly into chromosomes of some hardy crops (Lesney, 1999) and the production of herbicide and pest resistant plants by some seed companies (Liu, 1999) are some of the developments in the field of genetic engineering in the late 90s. Work on genetic engineering has continued in the 21st century. In 2000, scientists genetically modified food to increase its nutrient value for the first time (Azadi & Ho, 2010). More than twenty five genetically modified crops have received regulatory approval to date in the US (USDA, 2015). Adoption of GMOs in agriculture in developing countries particularly African countries is still very low. Natural Living (2015) confirm that only Zambia and South Africa are growing GMO crops.

RESEARCH METHODS AND REVIEW OVERVIEW

This study relied on extensive review of literature on genetic engineering applied to agriculture and or food production. We used literature published starting from the 20th century to date in gathering information suitable for the study. In order to unravel relevant literature for the study, a literature search of the ISI Web of Knowledge data base was performed in the fourth quarter of the year 2015. The research used a number of key words in searching for relevant literature (see Table 1).

Table 1: Key words used in literature search

Genetic engineering **and**	Environmental ethics
Ethics **and**	GM(O) foods
Environmental Ethics **and**	GM(O) Food, GM(O)food production, agriculture
GM(O), genetically modified foods **and**	Risks and benefits, environment, controversy

The list of phrases is however, not exhaustive as some other related phrases and/or word combinations were used to gather peer reviewed literature sources. The research gave little weight to grey literature. Over ninety percent of the literature cited in the paper is peer reviewed literature. This was done to have sound arguments verified by scientific research. Initially, the research gathered more than 300 journal articles, published between 1979 and 2015 in English. Further screening of the articles was done in order to remain with those articles with strong arguments on critiques of GMO foods based on possible environmental costs and benefits. In the end, a total of 72 articles were selected and used for this study, specifically for the environmental critiques of GMOs and background of the technology in food production. Majority of peer reviewed literature on environmental concerns of GMOs in agriculture were found in environmental ethics journals. Concern was only given to critiques of GMO in food production related to the environment i.e. protection, conservation, pollution or any other forms of damage to the ecosystem (both flora and fauna). In total, more than 72 research articles are cited in this paper. This is because some articles, not necessarily on GMOs were referred on some important aspects highlighted in the paper, one example of such being organic farming. Figure 1 shows distribution of articles cited (by year of publication) in this paper on background and environmental critique of GMO technology in agriculture.

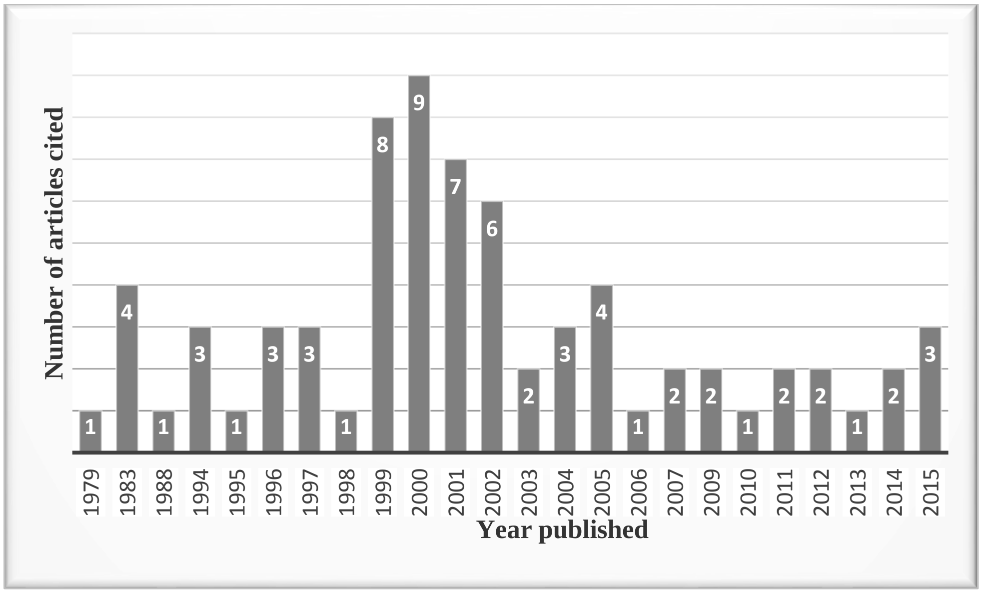

Figure 1: Distribution of articles cited on background and environmental costs and benefit of GMOs in agriculture

RESULTS AND DISCUSSION

After careful review of the final list of articles selected on critiques of genetic engineering in foods based on the potential risks and benefits to the ecosystem, the study found a number of perceived environmental costs and benefits.

Summary of environmental costs and benefits of GMO technology in agriculture

A summary of the major environmental costs and benefits is given in table 2.

Table 2: environmental costs and benefits of GMO in food production

Environmental benefits	Cited references
Increased productivity and reduced land degradation	Domingo, 2000; Wisniewski et al., 2002; Bawa & Anilakumar, 2013; Uzogara, 2000; Kuiper et al., 2002
Reduced application of herbicides and pesticides (hence less pollution from excessive use of the chemicals)	Wood, 1995; Uzogara, 2000; Kuiper et al., 2002.
Reduced gross waste associated with transportation and waste of fruits and vegetables	Uzogara, 2000; Bawa & Anilakumar, 2013.
Use of GMO plants in bioremediation	Gray, 1998.
Environmental costs	
Escape of genes into the ecosystem resulting in unwanted changes within the ecosystem	Barling, 1996; Conner et al., 2003; Pilson & Prendeville, 2004; Martin & Creswell, 2007; Gregorowius, 2012.
Compromising species biodiversity values	Barling, 1996; Conner et al., 2003; Pilson & Prendeville, 2004; Gregorowius, 2012.
Direct and indirect effects on un-targeted species in the ecosystem	Oger et al., 1997; Losey et al., 1999; Lesney, 1999; Moffat, 2000; Godfrey, 2000; Hellmich et al., 2001; Oberhauser et al., 2001; Pleasants et al., 2001; Zangerl et al., 2001; Stanley-Horn et al., 2001; Malone et al., 2000; Marvier, 2002; Conner et al., 2003; Harwood et al., 2005; Gregorowius, 2012.
Increased release of toxins into the environment	Firbank & Forcella, 2000; Watkinson et al., 2000; Brookes & Barfoot, 2013; Hails, 2009
Concern on animal rights	Kaiser, 1996; Dyer, 1996; Wilmut et al., 1997; Koenig, 1999; Lassen et al., 2006; Ormandy et al., 2009; Hails, 2009; Azadi & Ho, 2010.

Environmental benefits of GMO application to agriculture

There are some perceived environmental benefits of the application of genetic engineering to food production or agriculture. We discuss some of the perceived benefits revealed by literature in this section. Basically the benefits include: improved productivity using less land for cultivation; possibility of reducing the need for pesticides and other chemicals which could decrease release of toxins exposure to the environment; and the potential of producing longer shelf life fruits and vegetables that could decrease gross waste associated with transportation and storage.

Increase in crop productivity is one of the benefits GMO technology has brought to food production in developed countries (Domingo, 2000; Wisniewski et al., 2002; Bawa & Anilakumar, 2013). Productivity is improved by making plants yield higher when compared to conventional farming, and making them tolerant to pest, weeds, herbicides, viruses, insects, salinity, pH, temperature, frost drought and weather (Uzogara, 2000). Environmental benefit is achieved mainly because of the reduction in application of pesticides and herbicides and less land degradation through erosion as GMO plants are said to be grown on smaller pieces of land when compared to conventional farming (Uzogara, 2000; Kuiper et al., 2002 Azadi & Ho, 2010). Wood (1995) pointed out that insect resistant fruits such as apples, virus resistant cantaloupes, cucumbers, herbicide tolerant corn, tomatoes, and soybeans are some of the successful applications which have yielded environmental benefits. In addition, GMO in food production will produce fruits and vegetables with a longer shelf-life thereby reducing gross waste associated with transportation and waste (Uzogara, 2000; Bawa & Anilakumar, 2013). This is a potential benefit for environmental protection as this could reduce solid waste accumulation especially in developing country cities. Moreover, Gray (1998) noted that GM plants can be very useful in bio-remediation as they can be used to remove industrial waste and improve recycling of toxic chemicals.

Environmental costs of GMO technology application to food production/agriculture

The study found out that the major threats to the natural ecosystem and hence environmental sustainability include the following; escape of genes into other species in the ecosystem resulting in unwanted changes within the ecosystem (e.g. escape of genes through cross-pollination with other plant species in the ecosystem); risks to non-targeted animal species e.g. birds, insects and possible disturbances and risks to food chains and food webs in the ecosystem; damage to the environment through increased toxins discharged into the environment and possible uncontrolled damage to the ecosystem; the increased threats to the plant and animal species through experimentation, global warming potential and increase in energy use associated with GMOs use in agriculture.

The study revealed that the escape of genes into the environment/natural ecosystem is one of the major threats of GMO technology applied to food production or agriculture (Conner et al., 2003; Gregorowius, 2012; Pilson & Prendeville, 2004; Martin & Creswell, 2007). Agricultural production is directly linked with the natural environment, and if genes find their way out into other members of the ecosystem it is most likely that they will result in unwanted changes into the environment. The release of genes is feared that plants may invade natural habitats and as a consequence, compromise the biodiversity values of species (Barling, 1996; Conner et al., 2003; Gregorowius, 2012; Pilson & Prendeville, 2004). Imagine the costs of herbicide resistant genes finding their way into some plant species or weeds. Barling (1996) pointed out that alien genes and possibly antibiotic-resistant markers could spread in the natural ecosystem and result in undesirable effects. Cross-pollination of GMO crops with other species is another way genes can spread into the ecosystem (Martin & Creswell, 2007). This therefore implies that introduction of genetically modified organism technology in crop production may temper with the local environments and therefore disturb ecosystem services which happen to be a major source of livelihoods for the poor in most developing countries especially of Africa.

In addition, GMO technology applied to agricultural/food production can pose a threat to un-targeted species in the ecosystem. Insects or other organisms can be affected through exposure to GMO plant material due to toxicity (direct effect) or via the multi-trophic level food chains (indirect effect) (Losey et al., 1999; Lesney, 1999; Moffat, 2000; Godfrey, 2000; Conner et al., 2003; Gregorowius, 2012). Common cases of this effect have been experienced in *Bacillus thuringiensistoxin* (***Bt***) Maize. ***Bt*** maize pollen have been found to have some impact on the monarch butterfly population for example (Losey et al., 1999; Hellmich et al., 2001; Oberhauser et al., 2001; Pleasants et al., 2001; Zangerl et al., 2001; Stanley-Horn et al., 2001) and possibly other useful pollination agents. Another example of species affected by ***Bt*** maize is that of the honey bee (*Apis mellifera*) which is a beneficial insect highly involved in pollination. Malone et al. (2000) found out that at high doses, serine protease inhibitors inhibit bee gut proteases, which may result in reduced adult bee longevity. This therefore implies that GMO plant material also affects the natural food chains and food-webs. Effects of ***Bt*** maize pollen on insect species like butterfly and honey bees reduce the population of prey insect available in local environments and this disturbs the ecosystem, in its balance and species diversity. Another interesting example is that of GMO sugar beets that were produced to be resistant to herbicides and successfully reduce weeds. However, it was found that Skylarks birds that relied on the sugar beet seeds for survival were robbed of a reliable food source which endangered their existence (Gregorowius, 2012). Other species affected negatively by exposure and through the multi-level food chains (Marvier, 2002; Harwood et al., 2005) includes effect on rhizosphere bacterial populations (Oger et al., 1997; Godfrey, 2000), nematodes and springtail insects (Donegan et al., 1997) etc. (see Conner et al., 2003). It can be inferred that GMO plant material can have serious threats to the ecosystem through both direct and in-direct effects on plant and animal species, posing big threats to food chains, food webs and ultimately to the ecosystem.

The review also found that GMO application in food production/agriculture exerts further damages to the environment. One way cited to damage the environment is through increased release of toxins into the environment (Firbank & Forcella, 2000; Watkinson et al., 2000). Brookes & Barfoot (2013) found that pests and weeds that are herbicide-resistant inevitably emerge, which means that stronger, more quantities and more toxic chemicals will be needed to get rid of these pests. An example of herbicide resistant super weed case is that of herbicide resistant genetic engineering rape seed (canola) spreading their herbicide resistance traits to related weeds such as the wild mustard plants (Conner et al., 2003). In addition, laboratory and field tests have indicated that common plants and pests such as cotton bollworms, living under constant pressure from genetic engineering crops, would evolve into super pests completely immune to ***Bt*** and other environmentally sustainable pesticides (Conner et al., 2003). Such a scenario will create a serious problem for the farmers and in trying to cope with the problem they may try excessive application of harmful pesticides thereby causing more damage to the environment. More so, unintended hybrid strains of weeds and other plants can develop resistance to these herbicides through cross-pollination (Martin & Creswell, 2007), thus negating the potential benefit of the herbicide as is the case with Glyphosate (Round Up). What is more worrisome from the application of GMOs and associated technologies in agriculture is that if these GMO crops do negatively impact the environment, the ability to contain/adapt to the rate of damage especially in poor communities in the developing world is limited. Gregorowius et al. (2012) mentioned that the impact is more likely to spread in an out of control fashion making it very difficult to adapt to, or stop, the damaging effects. An example noticed in literature is that of sugar beet, that had been engineered to be resistant to a specific herbicide but ended up having the genes resistant to a completely different herbicide (Conner et al., 2003).

Furthermore, the use of animal species in genetic engineering related experiments is also an issue of major concern. Studies have shown that animals being used in genetic engineering experiments (see Hammond et al., 2004; Lassen et al., 2006) are a potential threat to the ecosystem, first through reduction in rat populations and subsequent higher level animals in the food chain. Secondly, possibility of transfer of genes into the environment is also high when the rats are released into the environment. Ormandy et al. (2009) pointed out that the advancement of genetic engineering technologies has led to a rapid increase in the number and varieties of genetically engineered animals, particularly mice. The technology has been continually refined but genetic engineering techniques still remain inefficient, with many animals being exposed to harmful procedures (Lassen et al., 2006). Use of animals in experiments associated with GMO application to agriculture has also raised concern for animal rights groups (Kaiser, 1996; Dyer, 1996; Wilmut et al., 1997; Koenig, 1999; Azadi & Ho, 2010). It has also been shown that even in wildlife, application of genetic engineering causes more harm than good. The biggest fear associated with GMO food in this regard is that the harmful effects to individual species and the ecosystem as a whole maybe irreversible or rather costly to reverse.

Moreover, a review by Hails (2009) confirmed the negative impacts of GMO technology applied to food production on the environment. The study used several arguments such as biodiversity loss; global warming potential associated with GMOs; energy and material use associated with GMO products and wastes released to the environment (lifecycle assessment); strategies employed to delay or prevent build-up of pests and diseases resistance to the GM crop (refuse strategy) and a matrix-based approach to assess comparative sustainability and benefits and risks of the introduction of GMO products to agriculture (comparative sustainability assessment). The conclusion was that, GMO introduction in crop production may exacerbate degradation and decline in farmland and wildlife (ecosystem degradation).

IMPLICATIONS FOR SUSTAINABLE DEVELOPMENT POLICY IN AFRICA

What can be deduced from the costs and benefits of GMO technology in food production to the environment? From the results we can conclude that introduction of GMO in crop production bears more costs than benefits to the environment. This is mainly because of the fact that confirmed environmental costs pose huge threats to the natural ecosystems on which the majority of the population in Africa derive their livelihoods from (Munang et al., 2013; Suich, 2015). Main risks identified by the research to the environment due to the application of GMO technologies to food production/agriculture include; escape of genes into the environment that can invade natural ecosystems, contamination of non-targeted species, disturbances to the natural food chains and food webs, increasing toxins into the environment through chemical pollution, and increased threats to animal species due to increased experimentation with animal species e.g. mice, and rats. Such costs to the environment offer a huge threat to livelihoods.

Introduction of GMO technologies in African economies, especially the least developed countries, has been highlighted to likely have negative significant effects on livelihoods. The ecosystems, e.g. terrestrial ecosystems, have been shown to provide life essentials which include food, fresh water, as well as livelihood means such as farming, forestry, hunting and fishing to the world's poor living especially in developing countries. Moreover, often naturally occurring habitats often provide life-saving protection from droughts, diseases, famine and flooding (Munang et al., 2013). This therefore shows that increasing adoption of GMO technologies that can possibly degrade the environment further can pose serious threats to humanity especially in least developed countries that rely much on their surroundings for survival. This is further worsened by the fact that resource-constrained farmers (mostly found in developing countries) are known to be vulnerable when it comes to adapting to shocks (Hsu et. al., 2005; Sokona & Denton, 2001). It therefore means that containing the unexpected adverse effects of GMO plants and animals will be a great challenge that will further impact negatively on the livelihoods of the people and their environment. In developing country economies e.g. in sub-Sahara Africa, agricultural production is dominated by smallholder farmers (Graaf et al., 2011), who contribute more than 70% of food production in the economy. Domination of smallholder agriculture in most of the developing country regions in Africa implies that risks associated with GMO introduction will exacerbate the negative environmental impacts. This will mainly be as a consequence of less adaptive capacity and ability to cope with shocks expected to come along with the introduction of GMO plants and animals in agriculture, coupled with an overreliance on the natural ecosystem for survival. This even magnifies the risks to the environment associated with GMO introduction in agriculture.

Even though the analysis has shown some positive environmental benefits of GMO introduction in agriculture, uptake of GMOs in developing agriculture based on the environmental benefits is, to a large extent, irrational considering the availability of alternative environmentally friendly options. Environmentalist have strongly advocated for organic farming as an alternative to GMOs (Franks, 1999). Delate (2013) claims that growing advocacy for adopting organic farming in developing countries at the expense of GMOs is mainly due to the potential risks of GMOs which include huge environmental costs that developing countries may fail to cope with. Organic farming will be a more environmentally better option because it promotes; biodiversity (Meacher, 2000; Nutiva, 2002; Greenthumb, 2002, Foodware, 2002, Randerson, 2004; Das, 2004), saving of water resources (Sustainable Enterprises, 2002; Nutiva, 2002; Foley, 2006), working with nature in harmony (Nutiva, 2002; Trewavas, 2004), less chlorine chemistry into the environment (Sustainable Enterprises, 2002), reduction in pollution (Cacek & Langner, 1986; Lampkin & Midmore, 1999), energy conservation (Lampkin & Midmore, 1999; Holden, 2004), conservation of insect species (Greenthumb, 2002; Nutiva, 2002), soil fertility enhancement (Cacek & Langner, 1986; Lampkin & Midmore, 1999; Greenthumb, 2002), reduction of soil erosion (Nijhoff & Anderson, 2001; Sustainable Enterprises, 2002; Geherman et al., 2003), improvement of animal welfare (Foodware, 2002; Holden, 2004), conservation of flora and fauna (Lampkin & Nidmore, 1999; Balfour, 2003), serving wildlife (Holden, 2004; Foley, 2006) and less disease infestation to plants and animals (Azadi & Ho, 2010). However, organic farming is regarded to pose a threat to the environment as it promotes pro-intensive tillage practices (Peters, 2003). Besides, adoption of other environmentally smart agricultural practices such as conservation farming are also considered to be better, options for farmers in poor countries (Archer et al., 2007).

Finally, it is apparent that the introduction of GMO technology in food production in Africa bears high costs associated with destruction of natural habitats, costs of which may be extreme especially in Africa, where a significant proportion of the population depends on natural and semi-natural ecosystems for their survival which in itself puts pressure on the resources. It therefore means that GMO technology is likely to upset rather than reinforce sustainable agricultural systems in developing countries. We however, accept the fact that bio-engineering is a powerful and promising technology that offers both benefits and dangers to the environment as shown by the results. However, biotechnology research should proceed with precautionary principles in mind. For example, before application of the technology in Africa where agriculture is dominated by small-scale and resource-poor farmers, governments should ask themselves the following questions: Is the new technology necessary?, Does the technology promote safe and effective practices?, Can possible effects to the environment be traced and reversed? Can the technology be regulated? Most importantly, they should take into cognisant the long term and short term effects on the ecosystems and on animal welfare.

Fox (1999) stressed the point that ethics of preserving the earth's bio-integrity must promote or constrain genetic engineering in sectors such as agriculture. Research findings suggest prioritizing the earth's bio-integrity in vital sectors such as agriculture in Africa. However, we accept that the final decision by African governments to uptake or discredit adoption of GMOs in agriculture should carefully consider all aspects i.e. environmental, socioeconomic, health, and food security aspects involved.

CONCLUSION

For sustainable agricultural development in the developing world especially Africa, this review suggest giving more weight to possible environmental concerns of GMO technologies in food production. This is mainly because GMO technologies applied to agriculture are more likely to harm natural ecosystems in Africa which happen to support a huge proportion of the population in terms of livelihoods especially in rural areas. Ecosystems contribute to decent livelihoods for millions in the region while providing clean air and water, conserving biodiversity and mitigating climate change. Ensuring attainment of sustainable development goals in the region will need careful consideration of the risks associated with introducing the technology in agriculture. Action against the potential risks to the ecosystem will be important in minimizing drawbacks in current efforts meant to end poverty and hunger, ensure sustainable production and consumption and halt biodiversity loss in the region. In addition, unexpected effects of the technology in African agriculture may have greater negative impact because of the low adaptive capacity of the majority of the food producers (smallholder farmers) to shocks. In this case the technology can be a huge threat to environmental sustainability and sustainable development in the region. However, for a final decision on adoption of GMO's in Africa African governments should also factor in other potential socioeconomic, health, and food security aspects associated with the technology.

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REFERENCES

Archer, E., Mukhala, E. Walker, S. Dilley, M. and Masamvu, K., (2007). "Sustaining agricultural production and food security in Southern Africa: an improved role for climate prediction*?" Climatic Change* 83:287–300. DOI 10.1007/s10584-006-9192-5.

Azadi, H & Ho, P (2010). "Genetically modified and organic crops in developing countries: A review of options for food security". *Biotechnology Advances*. 28:160–168.

Balfour, E. (2003). Land health. Available on: http://www.sheepdrove.com/article.asp? art_id=111. Accesses 15 November 2015.

Balzer, P., Rippe, K. P., & Schaber, P. (2000). "Two concepts of dignity for humans and non-human organisms in the context of genetic engineering". *Journal of Agricultural and Environmental Ethics*, 13(1):7–27.

Barling, D. (1996). "Environmental sustainability or commercial viability? The evolution of the EC regulation on genetically modified foods". *European Environment*, 6: 48-54.

Bawa, A.S., and Anilakumar, K.R. (2013). "Genetically modified foods: safety, risks and public concerns—a review". *Journal of Food Science Technology* 50(6):1035–1046. DOI 10.1007/s13197-012-0899-1.

Bevan, M.W., Flavell, R.B., Chilton, M.D. (1983). "A chimaeric antibiotic resistant gene as a selectable marker for plant cell transformation". *Nature* 304: 184–7.

Brookes, G., & Barfoot, P. (2005). "GM crops: the global economic and environmental impact—the first nine years 1996–2004".*Ag Bio Forum*, 8(2&3):187–196.

Brookes, G., & Barfoot, P. (2013). "Key environmental impacts of global genetically modified (GM) crop use 1996–2011". *Biotechnology in Agriculture and the Food Chain* 4:2:109-119.

Cacek, T., Langner, L.L. (1986). The economic implications of organic farming. Available on: http://www.eap.mcgill.ca/MagRack/AJAA/AJAA_2.htm. Accessed 8 November 2015.

Clark, E. A., & Lehmann, H. (2001). "Assessment of GM crops in commercial agriculture". *Journal of Agricultural and Environmental Ethics*, 14(1), 3–28.

Conner, A.J., Glare, T.R. and Nap, J.N. (2003). "The release of genetically modified crops into the environment". *The Plant Journal*. 33, 19–46.

Cowgill, S. E., Danks, C., & Atkinson, H. J. (2004). "Multitrophic interactions involving genetically modified potatoes, non-target aphids, natural enemies and hyper parasitoids". *Molecular Ecology*, 13(3), 639–647.

Das, K. (2004). Organic: to combat pesticide residues; 2004. Available on: http://www.indiatogether.org/2004/mar/agr-organic.htm. Retrieved 28 October, 2015.

Deane-Drummond, C. E. (2004).*The ethics of nature*. Malden: Blackwell Publication.

Delate, K. (2013). What is organic agriculture? Leopold Center for Sustainable agriculture at Iowa State University.

Domingo, J.L. (2000). "Health risks of genetically modified foods: many opinions but few data". *Science* 288:1748–1749.

Donegan, K.K., Seidler, R.J., Fieland, V.J., Schaller, D.L., Palm, C.J., Ganio, L.M., Cardwell, D.M. and Steinberger, Y. (1997) "Decomposition of genetically engineered tobacco under field conditions: persistence of the proteinase inhibitor I product and effects on soil microbial respiration and protozoa, nematode and micro arthropod populations". *Journal of Applied. Ecology*. 34, 767–777.

Dyer, O. (1996). "Sheep cloned by nuclear transfer". *Br Medical Journal, 312*(7032):658.

Firbank, L. G., & Forcella, F. (2000). "Genetically modified crops and farmland biodiversity". *Science*, 289(5484), 1481–1482.

Foley CL. (2006) Making the organic connection; 2006. Available on: http://www. organicconnection.net/. Accessed December 01, 2015.

Foodaware. (2002). Organic farming and foods. Available on: http://www.net-consumers.org/food/03_02rev.htm. Retrieved 9 November 2015.

Fox, M., (1999), *Beyond evolution*. New York; the Lyons Press.

Fraley, R.T., Rogers, S.G., Horsch, R.B., Sanders, P.R., Rick, J.S., Adams, S.P., Bittner, M.L., Brand, L.A., Fink, C.L., Fry, J.S., Gallupi, G.R., Goldberg, S.B., Hoffman, N.L., Woo, S.C. (1983). "Expression of bacterial genes in plant cells". Proc Natl Acad Sci USA. 80:4803–7.

Franks, J.R. (1999). "The status and prospects for genetically modified crops in Europe". *Food Policy*. 24:565–84.

Geherman, V., Viraalt, R., Ellermae, O. (2003). "Comparison of leys on conventional and organic farms". *Agronomy Research* 2003; 1:11–6.

Godfrey, J. (2000). "Do genetically modified goods affect human health"? *Lancet*, 355, 414.

Graaff, J.D., Kessler, A. and Nibbering, J.W. (2011). "Agriculture and food security in selected countries in sub-Saharan Africa: Diversity in trends and opportunities". *Food Security* 3, 195–213.

Gray, S.N. (1998). "Fungi as potential bioremediation agents in soil contaminated with heavy or radioactive metals". *Biochem Soc Trans.* 26(4):666–70.

Greenthumb. (2002). Twenty-one year study documents the many benefits of organic agriculture. Available on: http://www.npsas.org/BenefitsOrg.html. Retrieved November 16, 2015.

Gregorowius, G., Lindemann-Matthies, P., Huppenbauer, M. (2012). Ethical Discourse on the Use of Genetically Modified Crops: A Review of Academic Publications in the Fields of Ecology and Environmental Ethics. *Journal of Agricultural and Environmental Ethics*, 25 (3), 265-293.

Hails, R. S. (2000). "Genetically modified plants—the debate continues". *Trends in Ecology & Evolution*, 15(1), 14–18.

Hails, R. S. (2002). "Assessing the risks associated with new agricultural practices". *Nature*, 418(6898), 685–688.

Hails, R. S. (2009). Environmental Impact of Genetically Modified Organisms (GMOs). eLS. DOI: 10.1002/9780470015902.a0003255.pub2.

Hammond, B., Dudek, R., Lemen, J., Nemeth, M. (2004). "Results of a 13 week safety assurance study with rats fed grain from glyphosate tolerant corn". *Food and Chemical Toxicology*. 42. 1003–1014.

Harwood, J. D., Wallin, W. G., & Obrycki, J. J. (2005). "Uptake of Bt endotoxins by non-target herbivores and higher order arthropod predators: Molecular evidence from a transgenic corn agro-ecosystem". *Molecular Ecology*, 14, 2815–2823.

Hellmich, R.L., Siegfried, B.D., Sears, M.K., Stanley-Horn, D.E., Daniels, M.J., Mattila, H.R., Spencer, T., Bidne, K.G. and Lewis, L.C. (2001). "Monarch larvae sensitivity to Bacillus thuringiensis purified proteins and pollen". Proc. *Natl. Acad. Sci. USA*, 98, 11925–11930.

Herrera-Estrella, L., Depicker, A., Van Montagu, M.L., Schell, J. (1983). "Expression of chimaeric genes transferred into plant cells using a Ti-plasmid-derived vector". *Nature.* 303:209–13.

Hinchee, M.A.W., Connor-Ward. D.V., Newell, C.A., McDonnell, R.E., Sato, S.J., Gasser, C.S., Fischhoff, D.A., Re, D.B., Fraley, R.T., Horsch, R.B. (1988). "Production of transgenic soybean plants during Agrobacterium-mediated DNA transfer". *Bio/Technology*. 53(5):50–3.

Holden, P. (2004). Organic advantages; 2004. Available on: http://www.guardian.co.uk/food/Story/0,2763,1213140,00.html. Accessed 15 November 2015.

Hsu, Y., Shyu, J.Z., Tzeng, G. (2005). "Policy tools on the formation of new biotechnology firms in Taiwan". *Technovation*. 25:281–92.

Isa, N.M., and Man, S. (2014) ''First Things First'': Application of Islamic Principles of Priority in the Ethical Assessment of Genetically Modified Foods. *Journal of Agriculture and Environmental Ethics* (2014). 27:857–870. DOI 10.1007/s10806-014-9504-0.

Kaiser, J. (1996). "Pests overwhelm Bt cotton crop". *Science* 273(5274):423.

Koch, K. (1998). "Food safety battle: organic vs. biotech". *Congressional Quarterly Researcher* 9(33):761–84.

Koenig, R. (1999). "European researchers grapple with animal rights". *Science* 1999; 284:1604–6.

Kuiper, H.A., Noteborn, H.P.J.M., Kok, E.J., Kleter, G.A. (2002). "Safety aspects of novel foods". *Food ResInt*. 35:267–71.

Lampkin N, & Midmore P. (1999). Organic farming and the European Union. Memorandum of evidence to the House of Lords select committee on the European community's sub-committee D (Agriculture, Fisheries and Food); 1999. Available on: http://www.aber.ac.uk/~wirwww/organic. Accessed 15 November 2015.

Lassen, J., Gjerris, M, Sandoe, P. (2006). "After Dolly — ethical limits to the use of biotechnology on farm animals". *Theriogenology*. 65:992–1004.

Lesney, M.S. (1999). "The Garden of Dr. Moreau: plant biotechnology as a chemical enterprise. Genetically modified foods are the fore-runners of designer chemical plants". *Today's Chemist at Work*. 8(6):28–33.

Liu, K. (1999). Biotech crops: products, properties and prospects. Food Technology, 53(5):42–9

Losey, J.E., Rayor, L.S., Carter, M.E. (1999). "Transgenic pollen harms monarch larvae". *Nature*.399:214.

Maghari, B.M., and Ardekani, A.M. (2011). "Genetically Modified Foods and Social Concerns. Avicenna" *Journal of Medical Biotechnology*, 3(3): 109–117.

Malone, L.A., Burgess, E.P.J., Stefanovic, D. and Gatehouse, H.S. (2000). "Effects of four protease inhibitors on the survival of worker bumblebees, Bombus terrestris L". *Apidologie*, 31, 25–38.

Martin, H. and Creswell, J.E. (2007). "The effect of wind direction on cross-pollination in wind-pollinated GM crops". *Ecological Applications* 17:1234–1243.

Marvier, M. (2002). "Improving risk assessment for non-target safety of transgenic crops". *Ecological Applications*, 12(4), 1119–1124.

Marvier, M., & Van Acker, R. C. (2005). "Can crop transgenes be kept on a leash?"*Frontiers in Ecology and Environment*, 3(2):99–106.

McMillan, M., Thompson, J.C. (1979). "An outbreak of suspected solanine poisoning in school boys: examinations of criteria of solanine poisoning". *Q J Med* 48: 227–43.

Meacher, M. (2000). Organic farming benefits biodiversity. Available on: http://wwwpan-uk.org/pestnews/pn48/pn48p15b.htm. Retrieved November. 14, 2015.

Moffatt, I. (2000). "A critique of ethical and social issues of genetically modified crops". International *Journal of Sustainable Development and World Ecology*, 7(3), 237–250.

Munang, R., Thiaw, I., Alverson, K., Liu, J., and Han, Z. (2013).3"The role of ecosystem services in climate change adaptation and disaster risk reduction". doi:10.1016/j.cosust.2013.02.002. Volume 5, Issue 1, March 2013, Pages 47–52 Terrestrial systems.

Natural Living (2015). List of Countries That Banned Genetically Modified Food. Available on: http://naturalrevolution.org/list-countries-banned-genetically-modified-food/: accessed 27 November 2015.

Nijhoff, P. and Andersson, A. (2001). Organic farming as a strategy for a multi-functional agriculture. Available on:www.naturraadet.dkorNaturraadet@naturraadet.dk. Accessed 16 November, 2015.

Nutiva. (2002). Ten good reasons to buy organic; 2002. Available on: http://www.nutiva.com/nutrition/organic.php. Accesses November 14 2015.

Oberhauser, K.S., Prysby, M.D., Mattila, H.R., Stanley-Horn, D.E., Sears, M.K., Dively, G., Olson, E., Pleasants, J.M. Lam, W.K.F. and Hellmich, R.L. (2001). "Temporal and spatial overlap between monarch larvae and corn pollen". *Proc. Natl. Acad. Sci. USA*, 98, 11913–11918.

Oger, P., Petit, A. and Dessaux, Y. (1997). "Genetically engineered plants producing opines alter their biological environment". *Nature Biotechn*.15, 369–372.

Ormandy, E.H., Schuppli, C.A., Weary, D.M. (2009). "Worldwide trends in the use of animals in research: The contribution of genetically modified animal models". *ATLA.* 2009; 37:63–68.

Peters, L.D. (2003). Sustainable farming needs bioengineering. Available on: http://www.yaledailynews.com/article.asp?AID=23774. Accessed on 15 November 2015.

Phillips, S.C. (1994). "Genetically engineered foods: do they pose health and environmental hazards?" CQ *Researcher.* 4(29):673–96.

Pilson, D., & Prendeville, H. R. (2004). "Ecological effects of transgenic crops and the escape of transgenes into wild populations. Annual Review of Ecology", *Evolution, and Systematics,* 35(1), 149–174.

Pleasants, J.M., Hellmich, R.L., Dively, G.P., Sears, M.K., Stanley Horn, D.E., Mattila, H.R., Foster, J.E., Clark, T.L. and Jones, G.D. (2001). "Corn pollen deposition on milkweeds in and near cornfields". *Proc. Natl Acad. Sci. USA*, 98, 11919–11924.

Randerson, J. (2004). Organic farming boosts biodiversity. Available on: http://www.newscientist.com/article.ns?id=dn6496. Accessed on 4 November 2015.

Robinson, J. (1999). "Ethics and transgenic crops: A review". *Electronic Journal of Biotechnology*, 2(2), 71–81.

Sandler, R. (2007).*Character and environment. A virtue-oriented approach to environmental ethics*. New York: Columbia University Press.

Schardt, D. (1994). "Brave new foods (genetically engineered foods)". *Amer Health*. 13 (1):60.

Shelton, A. M., Zhao, J.-Z., & Roush, R. T. (2002). "Economic, ecological, food safety, and social consequences of the deployment of Bt transgenic plants". *Annual Review of Entomology*, 7(2002), 845–881.

Snell, C., Bernheim, A., Bergé J-B, Kuntz M, Pascal G, Paris A, Agnès ER (2012). "Assessment of the health impact of GM plant diets in long-term and multigenerational animal feeding trials: a literature review". *Food Chem Toxicol* 50:1134–1148.

Sokona, Y., & Denton, F. (2001). "Climate change impacts: Can Africa cope with the challenges?"*Climate Policy*, 1, 117–123.

Stanley-Horn, D.E., Dively, G.P., Hellmich, R.L., Mattila, H.R., Sears, M.K., Laura, R.R. Jesse, C.H., Losey, J.E., Obrycki, J.J. and Lewis, L.(2001). "Assessing the impact of Cry1Ab-expressing corn pollen on monarch butterfly larvae infield studies". *Proc. Natl. Acad. Sci. USA*, 98, 11931–11936.

Suich, H., C. Howe, and G. Mace (2015). "Ecosystem services and poverty alleviation: A review of the empirical links", *Ecosystem Services*, vol. 12, pp. 137-147.

Sustainable Enterprises. (2002). What's so important about organic? Available on: http://www.sustainableenterprises.com/Body/organic.htm. Retrieved 10 November 2015.

Sustainable Pulse (2015). GM Crops Now Banned in 38 Countries Worldwide – Sustainable Pulse Research, http://sustainablepulse.com/2015/10/22/gm-crops-now-banned-in-36-countries-worldwide-sustainable-pulse-research/. Accesses on 22 October 2015.

Thayer, A.M. (1994). "FDA gives go-ahead to bio-engineered tomato". *Chemical & Eng News* 72:7–8.

Trewavas, A. (2004). "A critical assessment of organic farming-and-food assertions with particular respect to the UK and the potential environmental benefits of no-till agriculture". *Crop Protection*. 23:757–81.

USDA (2015)"Adoption of Genetically Engineered Crops in the U.S.". Economic Research Service. USDA. Accesses 12 November 12, 2015.

Uzogara, S., G. (2000). "The impact of genetic modification of human foods in the 21st century: A review". *Biotechnology Advances 18* (2000) 179–206.

Verhoog, H., Matze, M., van Bueren, E. L., & Baars, T. (2003). "The role of the concept of the natural (naturalness) in organic farming". *Journal of Agricultural and Environmental Ethics*, 16(1), 29–49.

Verma, C., Nanda, S., Singh, R.K., Singh, R.B., Mishra, S (2011). "A Review on Impacts of Genetically Modified Food on Human Health". *The Open Nutraceuticals Journal*, 2011, 4, 3-11.

Von Wartburg, W. P., & Liew, J. (1999).*Gene technology and social acceptance*. Lanham, Md: University Press of America.

Watkinson, A. R., Freckleton, R. P., Sutherland, W. J., & Robinson, R. A. (2000). “Predictions of biodiversity response to genetically modified herbicide-tolerant crops”. *Science*, 289(5484), 1554–1557.

Weaver, S. A., & Morris, M. C. (2005). “Risks associated with genetic modification: an annotated bibliography of peer reviewed natural science publications”. *Journal of Agricultural and Environmental Ethics*, 18(2), 157–189.

Wickson, F. (2014). “Environmental protection goals, policy & publics in the European regulation of GMOs”. *Ecological Economics*, 108 (2014); 269–273.

Wilmut I, Schnleke, A.E., McWhir, J., Kind, A.J., Campbell, K.H.S. (1997). “Viable offspring derived from fetal and adult mammalian cells”. *Nature*. 385(6619):810–3.

Wisniewski, J, Frangne, N., Massonneau, A., Dumas, C. (2002). “Between myth and reality: genetically modified maize, an example of a sizeable scientific controversy”. *Biochimie* 84:1095–103.

Wood, M. (1995). Boosting plant’s virus resistance: genetic engineering research could yield a safe way to produce hardy new plants. Agricultural Research, 43:18–20.

Zambrynski, P., Joos, H., Genetello, C., Leemans, J., Van Montagu, M., Schell, J. (1983). “Ti-plasmid vector for the introduction of DNA into plant cells without alteration of their normal regeneration capacity”. *Embo J.* Vol. 2:2143–50.

Zangerl, A.R., McKenna, D., Wraight, C.L., Carroll, M., Ficarello, P., Warner, R. and Berenbaum, M.R. (2001). “Effects of exposure to event 176 Bacillus thuringiensis corn pollen on monarch and black swallowtail caterpillars under field conditions”. *Proc. Natl. Acad. Sci*. USA, 98, 11908–11912.

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