Organisms
Journal of Biological Sciences

RESEARCH HIGHLIGHTS

Vol. 2, 1 (JULY 2018)
ISSN: 2532-5876
DOI: 10.13133/2532-5876_3.13
Open access article licensed under CC-BY

Evidence-based science or science-based evidence? The GM crops between false myths and ecological systems

Carlo Modonesi [a] and Fausto Gusmeroli [b]

[a] *Department of Chemistry, Life Sciences and Environmental Sustainability, University of Parma, Italy*

[b] *Department of Agricultural and Environmental Sciences, University of Milano, Italy*

Corresponding author: Carlo Modonesi modonesi@unipr.it

Abstract

In just over two decades, genetically modified (GM) crops have increased their global spread at an incredible rate. In the same period, research studies and reviews on their effects and performance have gradually become more frequent. Still today, however, there is a substantial lack of established evidence on GM crops mainly due to deontological, epistemological and methodological distortions that characterize much of the scientific production in this area of life sciences. As a consequence, the real impact of GM crops remains largely unclear and problematic. This situation challenges all promotional campaigns carried out by agribusiness companies. We address some issues related to GM crops and their impact, trying to highlight some obstacles that still prevent us from clarifying what we know, what we do not know and what we will never know by using unreliable scrutiny criteria. GM crops are still a source of heated debate within the scientific community and in public opinion. In many parts of the world, citizens are wary about biotech agriculture and foods. At international institutional level, it does not seem possible to develop an integrated framework of cultural and scientific principles capable of promoting the public interest. What is missing, above all, is the ability to incorporate uncertainty into the decision-making process, without hoping that an unlikely scientific consensus will develop on GM crops.

Keywords: GM crops, Bt corn, Meta-analysis, Ecosystems, Environmental Risk, Uncertainty

Citation: Modonesi, C, & Gusmeroli, F, 2018, "Evidence-based science or science-based evidence? The GM crops between false myths and ecological systems", *Organisms. Journal of Biological Sciences*, vol. 2, no. 1, pp. 63-71. DOI: 10.13133/2532-5876_3.13.

1. Introduction

Genetic engineering technologies based on gene transfer[1] have been used in industrial agriculture since the mid-1990s to protect crops and reduce yield losses. Over the period 1996 to 2016, twenty-six countries have authorized and adopted these crops. To date, 18 million farmers around the world grow engineered plants accounting for a total area of 185.1 million hectares. In 2016, the major GM crops in terms of planted area were corn, soybean, canola and cotton. Among them, soybean shows the most important planted area with 91.4 million hectares, corresponding to half of the global GM crops and 78% of the total soybean production worldwide (ISAAA, 2016).

In the last years, developing countries have planted more GM crops than the developed countries. At present, nineteen developing countries account for 54% (99.6 million hectares) of the global biotech area, while seven developed countries account for 46% (85.5 million hectares). According to ISAAA (2016), the increasing trend of the GM crops trade is expected to continue in the next years, especially in the Southern hemisphere.

[1] This contribution refers to GM crops obtained by transgenesis.

The ten most important countries producing GM crops are the following: USA, Brazil, Argentina, Canada, India, Paraguay, Pakistan, China, South Africa and Uruguay. Spain and the Czech Republic represent the two members states of the European Union with a significant biotech agriculture, with a total surface area of around 0.1 million hectares.

It is suspected that the cultivation of genetically modified plants involves a relevant number of ecological and agronomic risks, while other risks could be linked to the human consumption of GM products or their derivatives. In the European Union (EU), GM food and feed have been subjected to a science-based risk assessment before being placed on the market. In general, this process follows a multi-step approach to check the human, animal and environmental safety of GM products. The main engineered crops traded on the international market include corn, soybean, cotton, canola, sugar beet and alfalfa. To date, the transgenic events that have been successful in agriculture are associated only with two phenotypic traits: *i*) tolerance to herbicides and *ii*) resistance to insects (the second of which is of greater interest in this contribution). In the first case, the genetic modification makes the plant able to develop the tolerance to glyphosate or glufosinate. This phenotypic trait prevents cultivated GM plants from being killed when herbicides are applied to eliminate weeds. In the second case, the introduction of a microbial gene in the plant's genome allows the plant to express an insecticidal protein (Cry toxin or Bt toxin) – usually synthesized by the soil bacterium *Bacillus thuringiensis* (Bt) – to control pests such as corn borer (*Ostrinia nubilalis*) and other insects living in the agro-ecosystems (Wolfenbarger *et al*, 2008). It is worth noting that Bt toxin synthesized by bacteria can be very different in size and structure from Bt toxins produced by GM plants. The GM plants themselves produce different Bt toxins and the several Bt events of engineered crops grown around the world produce a number of distinct Bt toxins (Latham *et al*, 2017). This aspect would deserve more attention than usual, because when we talk about Bt crops it is not so obvious to know what we talk about. In the final part of this contribution, a critical reading of the recent meta-analysis by Pellegrino and Colleagues (2018) is proposed. From the title one would expect the article to be about GM corn broadly speaking, whereas actually the Authors focus exclusively on corn crops engineered to synthesize Cry proteins.

2. The unreal consensus on GM crops

Over the past two decades, a number of primary and meta-analytical studies have been performed to clarify the environmental and health impact of GM crops, as well as their possible benefits. These works were viewed as powerful tools to summarize primary research data on the effects of engineered plants in a standardized way. The concern of institutional agencies was to solicit academics to develop a scientific consensus on GM crops and foods and contribute to an evidence-based policy (Saltelli & Giampietro, 2017). In fact, two opposing tendencies – the strong economic pressures of biotech companies on one hand, and the alarmism mounting in public opinion on the other hand – were emerging especially in the EU, signaling the need for political action. This approach has been criticized by many authors for reasons related to the questionable assumptions and methodologies that characterize the investigation on GM crops risks, but also because of the crisis of reproducibility and governance of science warned by many scientists (Ioannidis, 2005; Saltelli and Funtowicz, 2017). The causes of this multifaceted crisis seem to be neglected by most commentators and decision makers, even if a public discussion on the subject seems to be urgent due to problems posed by the determinist/reductionist approach still dominant in life sciences (Lewontin, 1991; Lewontin & Levins, 2007), as well as the crisis of trust in political and technical institutions. Just to give an example of the last point, see the recent case concerning the authorization of the herbicide glyphosate in the EU and the controversies that followed the hard dispute between EFSA (European Food Safety Authority) and IARC (International Agency for Research on Cancer). An open dialogue between scientists and citizens is obviously an essential ingredient of a democratic society. However, in order to develop this dialogue on the basis of a transparent and collaborative attitude, it is necessary to remove a misunderstanding that still prevents a balanced relationship between science and society, namely the idea that the scientific enterprise operates on the basis of a consensus within the scientific community (Hilbeck *et al*, 2015; Saltelli *et al*, 2017).

3. Meta-analysis: uses and misuses

Meta-analysis means "analysis of analyses" and its use is suitable for analyzing the results of multiple studies on a specific topic (Glass, 1976). The first step of a meta-analysis should be the formulation of a clear and targeted research question, while the later stages should help to provide an equally clear and targeted answer. The use of meta-analyses is easier in the biomedical than in non-biomedical sciences because of the greater possibilities of standardizing the experimental conditions, methodologies and design. This is the reason why this type of research has been mainly applied to evaluate the effectiveness of pharmacological treatments (e.g. treatment *vs* placebo) and other interventions for clinical and therapeutic purposes (Marvier, 2011). The meta-analytical procedure should allow for an effective synthesis of primary studies, improving accuracy and minimizing errors, while assuring the transparency of methodologies. Furthermore, this approach should help to formally evaluate the rigor of primary investigation, checking for possible biases. Nowadays, meta-analytical reviews are considered the "gold standard" in providing evidence-based indications emerging from scientific research (Ashcroft, 2004). As a consequence, the approach has been expanded from biomedicine to other fields to inform decision-making in the areas of risk management and environmental safety, and to produce scientific evidence on the ecological impact of GM crops (Kohl *et al*, 2015). A broader use of meta-analysis, however, is not free from troubles and risk of manipulation.

The biostatistician and methodologist John Ioannidis, now at Stanford University, claimed that most of the studies published in the scientific literature are false (2005). In his work, the Author listed a number of critical issues traceable through scientific publications, stating that their actual prevalence and distribution among various fields is difficult to evaluate. This problem involves not only the primary studies but also meta-analytical reviews reported in the literature (Fanelli *et al*, 2017).

Among the documented troubles emerging from primary and secondary studies, some deserve particular attention. For example, a research finding is less likely to be true when the studies conducted in a particular field have a limited size, when the effect size is small, or when there is a great flexibility in designs, definitions, outcomes, and analytical procedures. The situation is the same when a research finding is subjected to a financial interest or other non-scientific goals. In this context, processing and translating outcomes of primary research into a reliable and more manageable information depends on the availability of unbiased original data.

The question of bias is fundamental in determining the output of a research. This kind of problem has nothing to do with other factors that may affect the results of an investigation, such as random error (variability) that leads some findings to be false by chance even when study design and data analysis are perfect. It is possible to reduce random error by increasing the sample size or pooling data of comparable studies in a meta-analysis. It is much more difficult to handle other distortions that undermine the reliability of a research. Bias refers to a systematic error that cannot be adjusted by increasing the sample size. Typical examples of bias can be represented by flawed selection of data, unsuitable endpoints, or epistemological misconceptions. As claimed by Ioannidis, "many scientific discoveries could simply be accurate measures of a prevalent bias" (2005). When these conditions characterize the results of primary research, the targeted question on which a meta-analysis is based cannot be answered.

4. Presumed certainty and unavoidable uncertainty

An important issue connected with the differential effectiveness in using meta-analyses in biomedical and non-biomedical sciences depends on operational factors. For example, while the health of human beings can be well defined and measured and bad outcomes can be readily identified by clinical symptoms and parameters (i.e. disease and death), the ecosystem's health is not so simple to define and measure. In the case of environmental damage caused by unsafe agricultural practices or products, the definition of an appropriate comparison or control treatment might be a very hard task (Marvier 2011). This could be a non-trivial challenge when we need to define and estimate risks. Risk evaluation applies to a situation where a probability distribution can be assigned to a given set of possible outcomes. This implies an information space used to represent the behavior of the system under observation. In addition, it requires that we can describe what will happen at a given point in space and time and the possible errors of our predictions (Giampietro, 2002). When addressing the ecological risk arised by technological factors about which our information is scarce, as in the case of GM crops, a high level of uncertainty is unavoidable: a principle that applies whenever a system governed by non-linear dynamics is disturbed. This does not mean that the investigation on environmental risks is an impossible task; it simply reminds us that our predictive ability could be very low when we deal with complex dynamics. Accepting uncertainty means to be aware that it is not possible to predict the behavior of a system with a satisfactory precision, especially when the disturbance does not fall in the category of perturbing factors historically experienced. In other words, the uncertainty depends on both the inherent indeterminacy of complex systems and the possible fallacy of our knowledge in forecasting future events. Knight made a clear distinction between "risk" and "uncertainty": in the first case, it is possible to use previous experiences to infer future events, while in the second case such an inference is not possible (Knight, 1964). From this point of view, growing GM plants in open field shows many analogies with nuclear accidents, climate change and water pollution due to new toxicants. The awareness of uncertainty and the difficulty of predicting clear results represent two basic principles of the contemporary science. They are fundamental when science is used to guide or influence evidence-based policies.

5. Ecosystems and impact of GM crops: what evidence?

With this contribution, we do not aim to question the undeniable usefulness of meta-analytical exploration as a whole. We just want to highlight the distorted use of meta-analyses that have sometimes been done to assess the environmental and health impact of GM crops. Our initiative aims to underline that, to date, the scientific literature on GM crops has often been characterized by investigations based on insufficient and/or inadequate data. In our opinion, the difficult process of clarifying the problems caused by GM crops has suffered from an over-simplification of the reality.

As mentioned earlier, in the development of a meta-analysis researchers compare the measurements found in many different studies. However, before addressing this task, researchers should check the appropriateness of those measurements for the specific problems they are facing. The meta-analytical procedure should be inspired by pragmatism and reflect the real conditions occurring in the natural environment, not only providing statistically significant results (Belovsky *et al*, 2004). Otherwise, the results of a meta-analytic study could be coherent from the point of view of quantitative data processing but not suitable to provide a realistic picture of the phenomena that they should describe.

The analysis of the human impact on ecosystems involves the emerging properties of organisms, the patterns and times of their evolution, the dynamics of singular species populations and the interactions between populations of different species and their physico-chemical environment (Belovsky *et al*, 2004). Given the complexity of the ecological services potentially interested by human interventions, the safety (or biosafety) of biotech agriculture should be tested taking into account the organizational, spatial and temporal scales that underlie the functioning of the environmental system. We believe that the pretension to make simple generalizations on the performance of GM crops, based on limited temporal and spatial evidence, does not provide useful contributions to a real understanding of their ecological impact. Our knowledge of the interplay between environmental and societal dynamics is not advancing at an effective enough way to clarify the long-term and large-scale effects produced by economic activities. Too often environmental exploration is designed with little attention to the conditions of the real world, so that the results may have no practical and theoretical significance. Most of the work on the effects of GM crops shows an alarming lack of repeated studies in the same ecosystem over time and in different ecosystems. Researchers should not consider the results of some studies on engineered crops in a single environment, or in a single period, as applicable throughout all latitudes and all seasons. There is a high probability that these studies will be conducted under a very narrow range of the conditions occurring in nature (Harvey & Pagel, 1991). The enormous diversity of biological species and communities on Earth suggests there could be a plurality of dynamics occurring in different places and times. The lack or low number of test replications over time and space explains why much of the efforts to understand the effects of GM crops are destined to fail (Weiner, 1995; Marvier *et al*, 2007). This limited vision also means that most studies are still conducted without adequate awareness of the scale dynamics that researchers face in ecosystems (Belovsky *et al*, 2004). An evidence-based science always requires a science-based evidence.

6. Remove old answers and develop new questions

Evidence-based science and policy are increasingly viewed as indisputable duties of a modern society. However, the decision-making process to authorize the use of new and potentially hazardous devices cannot be based on technical evaluations alone, without including in the process other critical and equally important issues. With regard to GM crops, decision-making should depend also on an objective assessment of their ethical, social and political implications (Saltelli and Giampietro, 2017).

The power of our species, undoubtedly, reflects an advanced scientific and technical development. However, human society has changed not only on the thrust of science and technology, although not everyone is willing to admit it. Today we have well-established tools and knowledge, as well as values and principles, that can lead to a more realistic understanding of the human-environmental relationship and to a reversal of its unsustainability. When evidence-based methodologies are used to support decision-making processes related to options whose effects on ecosystems and human health are unclear, the following questions should be considered. Would the analysis be feasible considering the complex dynamics and processes involved in the ecological evaluation of a potentially unsafe technology? Would this approach include reliable scrutiny criteria to provide indications compatible with sustainability? Would decision-making processes be open to citizens in planning the values, actions and objectives involved? Would the precautionary principle be an option in case of excessive uncertainty or lack of evidence?

Many investigations about the impact of engineered crops do not start from a reflection on the questions above. They often address scientific uncertainty and complex dynamics with a naive attitude that leads to unreliable conclusions. The lack of evidence on the effects is confused with the evidence of the lack of effects. Of course, researchers can be wrong, like any other human being, and they are not always aware of their mistakes. In other cases, researchers can have a legitimate interest in a particular result that leads them to mistake. Considerable experience in biomedical research has shown that where bias is present, it often leads to overestimating positive outcomes and to over-emphasizing the real benefits of an intervention (Ioannidis, 2005). Whenever the source of bias depends on conflicting interests, the integrity of science is threatened, while confusion increases in public opinion, and decision making cannot rely on an evidence-based knowledge (Saltelli and Giampietro, 2017).

7. The meta-analysis of Pellegrino and Colleagues: a synthetic focus

The recent meta-analysis of Pellegrino *et al* (2018) reveals important flaws that can also be identified in other studies on GM crops. From the point of view of the quantitative data processing, this meta-analysis shows no problems, even though, in general, it suffers from an over-simplification of the real world. This study seems to neglect the nature of the phenomena it aims to clarify. The Authors focus on the comparison between GM corn and conventional corn (non-GM lines) for different parameters (see below). For that purpose, they selected a number of peer-reviewed studies by performing keyword queries on the Web of Science Core Collection (Clarivate Analytics) database. The time window of the studies covers the period November 1996 - September 2016.

The first step in the recovery of scientific literature produced more than 6,000 publications, while the subsequent refinement gave less than 80 eligible works, covering respectively the following topics: performance and quality of crop; TOs (target organisms); NTOs (non-target organisms); and decomposition of soil biomass. The explanation given by the Authors for the massive exclusion of target articles from the initial selection is not clear**.** The general conclusions of Pellegrino *et al* (without providing details effects) can be summarized as follows:

- there is evidence that GM corn is more productive than conventional;
- GM corn is more effective against TOs infestation (data limited to *Diabrotica* spp.);
- lower concentrations of mycotoxins, fumonisins and trichothecenes are detected in GM corn;
- no substantial difference is observed by comparing the nutritional values of GM corn and conventional corn;
- the analyzed NTOs are not substantially influenced by GM corn (with the exception of *Braconidae*); the biogeochemical parameters, as the content of lignin in the stems and leaves, do not vary, while the biomass decomposition is higher in GM corn than in non-GM corn.

Below we propose some observations and opinions exclusively based on the contents of the paper of Pellegrino *et al*. Our comments reflect different problems we detected in the publication. In some cases these problems concern the study assumptions and procedures. In other cases, the problems depend on unclear or insufficient information. Otherwise, they depend on a lack of empirical evidence to provide any conclusions. The problems we have detected can be schematically summarized as follows:

I. This work is not based on the search for an answer to a single and targeted question. Rather, the purpose of the Authors is to compare the effects of a genetic engineering intervention (i.e. Bt events) on some different and not necessarily related parameters in corn crops. This does not fit the standard procedure and scope of a meta-analysis.

II. The reduction from over 6,000 to 79 targeted publications indicates a drastic exclusion of scientific articles and potentially useful data that requires a clear and comprehensive explanation. Otherwise, doubts that the selection procedure has been flawed by arbitrariness or that errors have occurred in the application of the eligibility criteria can be legitimately raised.

III. No mention is made about the possible conflicts of interest present in the research articles used for instructing the meta-analysis. Given the economic interests that gravitate around the GM crops, all studies funded or otherwise supported by private companies should be preventively excluded from the selected literature or explicitly reported in the meta-analysis. This could be a very critical point, potentially leading to invalidate all results of this meta-analysis.

IV. The meta-analysis relies on a very low number of studies. For each parameter only a few studies have been used, while single studies have been used for evaluating several parameters, weakening the final results. Any scientific conclusion based on such a poor evidence has an arbitrary significance.

V. An ecological view suggests that the effectiveness of the Bt toxin (as any other insecticide) in controlling pests is overestimated. Repeated consumption over time of the Bt toxin synthesized by GM corn does not necessarily reduce the abundance of insect pests for the following reasons:

- many pests killed by Bt toxin lead to much less food available for natural predators of pests. This reduces the population of predators, so that the final result is a shift in the cause of mortality of target organisms (the more they are poisoned and the less they are eaten) but not in their number;
- the lethal effect of Bt toxin can contribute to directly kill (by known or unknown mechanisms) a percentage even higher of predators of pests, with a further reduction of predator population. The result is that a high amount of insect pests could remain active in the fields due to a weakening of the ecological service provided by predators;
- the pressure on pest population due to the action of Bt toxin rapidly induces biological resistance to the toxin. Authors themselves admit that in a number of important taxonomic groups of pests "resistance and cross-resistance to Bt maize were recently detected". On the contrary, natural predators do not induce biological resistance (Levins, 1974).

VI. The development of biological resistance to insecticides allows the survival of a number of individuals within a population of pests. These individuals can replace the original population in a relatively short time because of the short biological cycles of pests. This factor can cause a neglected but important confounding effect when evaluating the "abundance" parameter in a population of OTs.

VII. Regarding the possible impact of Diabrotica, it is worth noting that this parasite causes corn damage only within a context of mono-succession. By substituting this cultivation with other plants every three years, the parasite can easily be controlled. This suggests that in the analyzed studies the conventional corn was grown with a single-product model, otherwise the presence of the parasite would not occur. Since the damage is essentially caused by the insect larvae and that it is limited to the roots, the presence of fumonisins in conventional hybrids must be ascribed to Ostrinia nubilalis or other factors (Magg et al, 2002).

VIII. The comparison of the two crop varieties (GM corn *vs* conventional corn) on TOs and NTOs is not adequately described, arising a problem of poor information. In their article, the Authors state: "All data utilized were collected in field experiments where no insecticide was applied", meaning – we suppose – that no treatment were performed on both GM corn and conventional corn. However, the statement "no insecticide was applied" says nothing about the pest management system implemented to grow conventional corn. The real conditions in which the control corn has been grown in the examined studies give an essential information to properly compare and understand the results obtained from the two crop varieties (Marvier *et al*, 2007). If no insecticide was used in conventional crops, different measures for pest control could have been used. Alternatively, if no pest management system has been used in conventional crops, then it is easy to explain why Bt corn yield is higher than conventional corn. Lacking information on pest management practices implemented in conventional crops, any conclusion on the parameters influenced by these practices is unfounded.

IX. The meta-analysis shows a map indicating the geographical distribution of field studies reported in the selected articles. However, the work does not clarify the real background conditions (e.g. the climatic context) in which the experiments were conducted. From the information provided in the article, one can assume that the experiments were not sufficiently replicated in different environments and at different times. As mentioned above, research on GM crops with insufficient test replication and inadequate spatial and temporal data cannot and should not be used to generalize the results (Marvier *et al*, 2007; Duan *et al*, 2008). The Authors themselves admit this limit by stating "there is need for more fieldwork with a wider geographical coverage and for having appropriate comparators and a field design that allows a solid statistical analysis". This point heavily weakens the results of the meta-analysis.

X. In assessing the effects on TOs and NTOs, the Authors use only a measure of abundance (i.e. the different number of individuals) of a given taxonomic group present in GM and conventional crops. Usually, this is performed to assess the impact on mortality of a toxin (i.e. Bt toxin) within a population. However, as shown by other field studies based on different *taxa*, end-points other than mortality should also be assessed, because sub-lethal effects of pesticides can trigger – both on TOs and NTOs – a wide spectrum of second-level (or higher) effects on wildlife (Elliott *et al*, 2011), returning a more realistic picture of the impact on food networks and ecosystem dynamics.

XI. The results of the meta-analysis lead the Authors to conclude that GM corn reduces human exposure to mycotoxins, which are notoriously related to carcinogenic risk. However, despite the term "toxicological" has been included in the title of the paper, the Authors are totally silent about the impact of GM corn on human health, implicitly suggesting the idea that the toxicological risk of GM corn depends only on the potential presence of mycotoxins. The health effects of GM food are difficult to assess for some inherent limits of biomedical research applied to human population. However, this does not mean "lack of effects", and caution should lead to pay more attention to the health issues. The scientific literature shows potentially serious health risks connected with the consumption of some GM foods (Nordlee, 1996); more generally, at the moment the impact of GM products, included Bt corn, on human health cannot be demonstrated or excluded (National Research Council, 2004; Bawa and Anilakumar, 2013; Benbrook and Landrigan, 2015).

XII. In comparing only GM corn and conventional hybrids, the meta-analysis focuses exclusively on industrial agricultural systems. The agroecological systems are excluded from the analysis and, as a consequence, also the comparison between GM and traditional corn seeds. Additionally, GM crops, like hybrids, are usually grown in the context of high-energy consuming and low-efficiency agricultural models. These models produce high water consumption, degraded soils, loss of agrobiodiversity and wild biodiversity; furthermore, they contribute to disperse synthetic pollutants in the environmental matrices and increase the farmer dependence on the power of the industrial agribusiness (Piementel *et al*, 2005; Benbrook, 2012).

XIII. Many other risks and evaluation criteria have not been mentioned in the work of Pellegrino *et al*. For example, the effects of Bt corn on soil ecology; the possible gene flow from GM corn to other (conventional or organic) corn crops; the risk of breeding with wild relatives and potential genetic impact on them (in terms of fitness advantages or damages); the risk of horizontal genetic events and their unpredictable implications. And so on. All these aspects are arbitrarily removed from the perspective of the Authors (Snow *et al*, 2005; Benbrook, 2012).

8. Conclusions

The work of Pellegrino *et al* shows many misconceptions and criticalities, but this is not a surprise. Other works published on the same subject are equally misleading. In our opinion, there is an ideological "bug" affecting most research on the impact of GM crops: an interesting subject for science sociologists and philosophers.

The problem is not only the quality of results produced by scientific research but something more general. Under its apparent impartiality and methodological rigor, the meta-analysis of Pellegrino *et al* actually does not find any significant evidence on the safety, sustainability and performance of GM corn. Another relevant (and worrying) aspect of the article lies in the distorted picture of the natural world that it proposes; a false representation that the mass media have re-launched with a great echo. This work has aroused the curiosity of newspapers in many parts of the Western world, but its results and conclusions have rarely been accompanied by a critical reading, able to grasp its numerous troubles. The misleading message that the future of agriculture depends exclusively on the "biotechnological improvement" of plants has probably reached the readers, even if this is mere mythology.

There are many arguments and reasons for believing that real things are not this way; and we think it is worth to spread them even if, in the collective imagination, reality is always less spectacular than fantasy.

As reported by Horton and Colleagues on *Lancet* (2014), the poor health state of the Planet urgently needs new lifestyles, new knowledge, and new awareness. Above all, it requires a social movement to sustain the expected transition toward sustainability. Sufficient food could be produced with less environmental and health costs, safeguarding ecosystems and their resilience. And we hope that even the science closest to the objectives of the agro-industry can realize the urgency of such paradigm shift.

Conflict of interest

The Authors declare no competing interests.

References

Ashcroft, RE, 2004, "Current epistemological problems in evidence based medicine", *Journal Medical Ethics*, 30:131-135, doi: 10.1136/jme.2003.007039.

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

Benbrook, C, 2012, "Impacts of genetically engineered crops on pesticide use in the U.S. – the first sixteen years", *Environmental Sciences Europe Bridging Science and Regulation at the Regional and European Level*, 2012, **24**:24, https://doi.org/10.1186/2190-4715-24-24.

Benbrook, C, Landrigan PJ, 2015, "GMOs, herbicides, and public health", *New England Journal of Medicine*, 373:693-695, DOI: 10.1056/NEJMp150566.

Belovsky, GE, Botkin, DB, Todd A. Crowl, TA, Cummins, KW, Franklin, JF, Hunter, ML, Joern, A, Lindenmayer, DB, MacMahon, JA, Margules, CR, Scott, MJ. 2004, "Ten suggestions to strengthen the science of ecology", *BioScience*, Vol. 54, Issue 4, 1, 345–351, https://doi.org/10.1641.

Duan, JJ, Marvier, M, Huesing, J, Dively, G, Huang, ZY, 2008, "A meta-analysis of effects of Bt crops on honey bees (Hymenoptera: Apidae)", *PLoS One*, 3(1): e1415, doi:10.1371/journal.pone.0001415.

Elliott, JE, Bishop, CA, Morrissey, CA (Eds), 2011, *Wildlife Ecotoxicology: Forensic Approaches*, Springer Science Business Media, LLC.

Fanelli, D, Costas, R, & Ioannidis, JPA, 2017, "Meta-assessment of bias in science", *Proceedings of the National Academy of Sciences*, vol. 114, no. 14, 3714-3719, doi/10.1073/pnas.1618569114.

Giampietro, M, 2002, "The precautionary principle and ecological hazards of genetically modified organisms", *Ambio*, Vol. 31, No. 6.

Glass, GV, 1976, "Primary, Secondary, and Meta-Analysis of Research", *Educational Researcher*, Vol. 5, No. 10, pp. 3-8.

Harvey, PH, Pagel, MD, 1991, *The Comparative Method in Evolutionary Biology*, New York: Oxford University Press.

Hilbeck, A, Binimelis, R, Defarge, N, Steinbrecher, R, Székács, A, Wickson, Antoniou, F, Bereano, PL, Clark, EA, Hansen, M, Novotny, E, Heinemann, J, Meyer, H, Shiva, V, & Wynne, B, 2015, "No scientific consensus on GMO safety", *Environmental Sciences Europe*, 27:4, DOI 10.1186/s12302-014-0034-1.

Horton, R, Beaglehole, R, Bonita, R, Raeburn, J, McKee, M, Wall, S, 2014, "From public to planetary health: a manifesto", *Lancet*, 8; 383(9920):847, doi: 10.1016/S0140-6736(14)60409-8.

Ioannidis, JPA, 2005, "Why most published research findings are false", *PLoS Medicine*, 2(8): e124.

ISAAA, http://www.isaaa.org, 2016.

Knight, FH, 1964, *Risk, Uncertainty and Profit*, A.M. Kelley, New York.

Kohl, C, Frampton, G, Sweet, J, Spök, A, Haddaway, NR, Wilhelm, R, Unger, S, & Schiemann, J, 2015, "Can systematic reviews inform GMO risk assessment and risk management?", *Frontiers in Bioengineering and Biotechnology*, vol 3, pp. 113, doi: 10.3389/fbioe.2015.00113.

Latham, JR, Love, M, Hilbeck, A, 2017, "The distinct properties of natural GM Cry insecticidal proteins", *Biotechnology and Genetic Engineering Reviews*, Vol 33, n. 1, https://doi.org/10.1080/02648725.2017.1357295.

Levins, R, 1974, "Discussion paper: the qualitative analysis of partially specified systems", *Annals of the New York Academy of Sciences*, Vol. 231, n. 1, pp. 123-138.

Lewontin, R, 1991, *Biology as Ideology: the Doctrine of DNA*, Harper Collins Publishers, New York.

Lewontin, R, Levins, R, 2007, *Biology under the Influence: Dialectical Essays on the Coevolution of Nature and Society*, NYU Press.

Magg, T, Melchinger, AE, Klein D, & Bohn, M, 2002, "Relationship between European corn borer resistance and concentration of mycotoxins produced by *Fusarium* spp. in grains of transgenic Bt maize hybrids, their isogenic counterparts and commercial varieties", *Plant Breeding*, vol 121, pp. 146-154.

Marvier, M, McCreedy, C, Regetz, J, Kareiva, P, 2007, "A meta-analysis of effects of Bt cotton and maize on non-target invertebrates", *Science*, vol 316, pp. 1475-1477.

Marvier, M, 2011, "Using meta-analysis to inform risk assessment and risk management", *Journal of Consumer Protection and Food Safety*, 6, Suppl 1:S113-S118, DOI 10.1007/s00003-011-0675-6.

National Research Council, Committee on Identifying and Assessing Unintended Effects of Genetically Engineered Foods on Human Health, 2004, *Safety of Genetically Engineered Foods: Approaches to Assessing Unintended Health Effects*, Washington, DC: National Academies Press.

Nordlee, JA, 1996, "Identification of Brazil-nut allergen in transgenic soybeans", *New England Journal of Medicine*, vol 334, pp. 688-692, doi: 10.1056/NEJM199603143341103.

Pimentel, D, Hepperly, P, Hanson, J, Seidel, R & Douds, D, 2005, "Environmental, energetic, and economic comparisons of organic and conventional farming systems", *BioScience*, vol 55, n. 7, pp. 573-582.

Pellegrino, OE, Bedini, S, Nuti, M, & Ercoli, L, 2018, "Impact of genetically engineered maize on agronomic, environmental and toxicological traits: a meta-analysis of 21 years of field data", *Scientific Reports*, *Nature* Publishing *Group*, vol 8, pp. 3113, doi:10.1038/s41598-018-21284-2.

Saltelli, A, Funtowicz, S, 2017, "What is science's crisis really about?", *Futures*, vol 91, pp. 5-11.

Saltelli, A, Giampietro, M, 2017, "What is wrong with evidence based policy, and how can it be improved?", *Futures*, vol 91, pp. 62-71.

Saltelli, A, Giampietro, M, Gomiero, T, 2017, "Forcing consensus is bad for science and society", *The Conversation*, (downloadable article) https://theconversation.com.

Snow, AA, Andow, DA, Gepts, P, Hallerman, RM, Power, A, Tiedje, JM, & Wolfenbarger, LL, 2005, "Genetically engineered organisms and the environment: current status and recommendations", *Ecological Applications*, vol 15, n. 2, pp. 377-404.

Weiner,J, 1995, "On the practice of ecology", *Journal of Ecology*, vol 83, pp. 153-158.

Wolfenbarger, LL, Naranjo, SE, Lundgren, JG, Bitzer, RJ, Watrud, LS, 2008, "Bt crop effects on functional guilds of non-target arthropods: a meta-analysis", *PLoS ONE*, vol 3, n. 5: e2118, doi:10.1371/journal.pone.0002118.