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ARTICLES

Uncertainties of Nutrigenomics and Their Ethical Meaning

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Abstract Again and again utopian hopes are connected with the life sciences (no hunger, health for everyone; life without diseases, longevity), but simultaneously serious research shows uncertain, incoherent, and ambivalent results. It is unrealistic to expect that these uncertainties will disappear. We start by providing a not exhaustive list of five different types of uncertainties end-users of nutrigenomics have to cope with without being able to perceive them as risks and to subject them to risk-analysis. First, genes connected with the human body or nutrients can have different functions in interaction with their environment (for instance, one nutrient can be healthy for the heart, but can also be a high risk in relation to cancer). Secondly, uncertainties are formed by risk analyses. Will it be possible to calculate a certain risk of getting a certain condition with a certain lifestyle? Will it be difficult to separate the genetic component and the lifestyle component? How high will these risks be? How will these risks be handled by the actors? In the case of personal genotyping, it is unclear how frequent an adverse polymorphism will occur. Will every individual have a certain vulnerability to a certain disease or will it only be applicable to a small group of the population or particular populations? Thirdly, dietary advices are subject to uncertainties and still to be developed professional standards: some will have adverse outcomes, some will not delay the disease, and some will assume uncertain associations between nutrients, lifestyle, and genetic vulnerabilities. Fourth, with regard to the usefulness of tests it is uncertain to what extent risks indications about obesity and diabetes and other vulnerabilities really influence people to live healthier and therefore will help to prevent these conditions. Fifth, it is uncertain how and what nutrigenomics products will be developed and used. Will it be possible to develop more effectively health improving products? Or is this too difficult and will nutrigenomics continue to be used in not always justified health claims as a commercial and marketing tool?

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Present-day ethics and theories of responsibilities presuppose that uncertainties will disappear and concentrate on what seems to be fixed and stable in science. We develop provisional thoughts that assume that the dynamic of science to produce uncertainties and dilemmas is endemic, and we stress the need for consumers to institutionalize value searching, exploring, and deliberating devices in the health and food sector to find out the most important uncertainties and correspondingly socially desirable research priorities.

Keywords Nutrigenomics · Health and food · Uncertainties · Food ethics

Introduction: Expectations and Disappointments of the Human Genome

Knowledge of the human genome has great potential for human health. It may help us to understand the origins of diseases and to tackle diseases more precisely by using medicines that work at the DNA level. Also for the nutritional sciences it possesses immense possibilities. For decades now epidemiologists have tried to find links between health and food. Research at genome level may help to reveal the relation between food and health. It could find the origins of diseases and help to prevent them. It may prove the healthy influence of nutrients. However, this potential is overshadowed by the enormous complexities surrounding the genome and the possible applications of genomics or, this paper's subject, nutrigenomics.

The DNA was thought to be the "language of God" (according to President Clinton) and the blueprint of the human body, concealing the secrets of life. If this blueprint would be uncovered we would "know" for certain. We would be able to solve the mysteries of our body and be able to prevent many killing diseases (for an example: Smith 2005; Stephenson 2008). However, when most of the human genome had been sequenced after 2000, this idea was shattered into pieces. The working of the humane genome and its interaction with the environment (like nutrients) are complex, which became already clear after only 22.000 genes were identified. Interactions between genes, enormous amounts of genes reacting on one nutrient and opposing reactions of genes triggered by the same nutrient make the challenges of nutrigenomics overwhelming (Piatigorsky 2007). Besides that it is rather difficult to test the health effect of nutrients and therefore certain diets and products, it also turns out that it is hard to determine the boundary between illness and health on the genetic level. Nutrients have to interact during a stage in which the body at that moment of time does not give any signals of illness yet (Van Roost 2005). The literature on the influence of nutrients on health is therefore replete with contradicting evidences (Davis and Milner 2004). It is no wonder that some food scientists express their scepticism about the scientific basis of health claims: "…the Food and Drug Administration's oversight over health claims has eroded, and the United States now allows 'qualified health claims' for which there is hardly any evidence, as long as a disclaimer is included." (Katan 2004, p. 181; compare Aggett et al. 2005)

Besides these complexities and uncertainties of the experimental results of nutrigenomics, nutrigenomics' interaction with society is largely unknown. How

will professional groups, like dieticians, supermarkets, general practitioners, respond to the development of nutrigenomics, its complexity and uncertainties? How will they influence its applications? Will the projected end-users be able to integrate nutrigenomics products and services, whatever they may be, in their daily life?

This short history of nutrigenomics shows us a rise and fall of expectations and certainties (for similar cycles see Brown and Michael 2003). The development of the science presents a dynamic in which "organized skepticism" (Merton 1968) follows "organized utopianism" (our wording, MK): taken for granted truth and certainties are destroyed or better, are unmasked as (un)truths and uncertainties. The persistent intellectual dispute among competing research teams in which established truths fall prey to critical scrutiny is an indication of the mature evolution of the scientific understanding of the world. Scientists claim the right to make promises *and* mistakes; that is the core of the scientific ethos (Merton 1968; Kuhn 1962; Pinch 2000).

This oscillating history shows that during the period of emerging paradigms or disciplines scientists are in need of an organizing utopian idea that rallies their energy and directs their attention. Organized utopianism (promises) seems necessary too and will give occasion to mistakes and false promises; organized skepticism will unmask them later. The history of science is full of these (later discovered) mistakes, which in some cases can turn out to be big problems or even catastrophes. Examples of serious mistakes made in agriculture and food sciences are the use of lead, of radioactivity, and DDT in agriculture and food, and the claim that all vegetable oils are seen to be healthy (Bryson 2003, Chaps. 7, 10).

Nutrigenomics is thus surrounded by internal and external uncertainties and it is for end-users wise to better prepare themselves for a genomics future with fundamental uncertainties than to expect that in the long run the uncertainties will disappear. The issue of uncertainties of genomics has been tackled earlier, e.g., from the perspective of policy making (Gottweis 2005; Pinch 2000), science management (Pinch 2000; Brown and Michael 2003) and theory of science (Brown and Michael 2003; Jasanoff 2005). Here we will concentrate on the impact of the uncertainties of nutrigenomics on citizen/consumers by exploring the fruitfulness of an ethical perspective that focuses on how citizens/consumers' cope with fundamental uncertainties.

Many ethical approaches to genomics or broader biotechnology have taken the development of genomics towards certainty for granted. They view the uncertainties of genomics as temporary, and discuss norms of how to regulate or even ban the expected products of this science without delving into the intricacies of the science. A good example is Fukuyama's proposal in his *Our Posthuman Future* (2002, p. 212) to put "brakes" on biotechnology. In this article we will concentrate not only on the products but on dynamics of genomics that constantly produces uncertain and dilemmatic situations. We will assume that such uncertainties are here to stay. What do they mean for consumers and citizens? How should citizens/consumers live with these dynamics of uncertainties of products and services of nutrigenomics, some of which are rather fundamental? How to select the more certain results from the hypes and the misleading ones? How to attribute

responsibility to purveyors of messages that contain a lot of uncertainty or are even completely hyped up? How to deal with the different normative expectations of the different stakeholders? How can citizens/consumers orient themselves in this always changing forest, similar to Macbeth's Birnam Wood?

The paper aims at spelling out the ethical meaning of the different types of uncertainties connected to nutrigenomics for the two main stakeholders: end-users (consumers) and scientists. We differ in our approach from the usual ethical approaches to science and technology that assume a fixed, stable, and consensual position of the nutrigenomics science and apply subsequently their ethical principles. First, we will start with spelling out five different types of uncertainties and complexities of genomics. Nutrigenomics is defined as the research that uses knowledge of the genome to prevent diseases or to improve health by means of food, and is quite complex, because it also tries to take into account non-human organisms that are involved with food intake and digesting (like bacteria). These complexities affect the types of the uncertainties surrounding the different branches of nutrigenomics. The uncertainties do not only arise due to discordant findings, but are more complex: cognitive uncertainties, i.e., uncertainties that arise from (social) scientific findings are linked with moral uncertainties, uncertainties that people encounter in dealing with the question what is the right thing to do in a certain situation. Secondly we will discuss these uncertainties in the light of theories of science and of postmodernity and how they align with other trends. Thirdly we will outline an ethics of uncertainty that enables citizens/consumers to live with more and less fundamental scientific uncertainties. Finally we will give an outlook how to cope with enduring genomics uncertainties.

Types of Uncertainties Surrounding Nutrigenomics, its Services, and Products

Nutrigenomics will probably and hopefully not give rise to big risks like the ones covered by Frankenstein trajectories; however, patients and consumers of nutrigenomics are confronted with a lot of uncertainties: uncertainties galore! Most of these uncertainties are not covered by the usual meaning of risks (size of harm times the probability, Amendola 2002) or by the term "incomplete information." Mostly, one can comprehend uncertainties, but the assessment of uncertainties is something different and not dependent on more information but, as we will show later, on ethical procedures, standards, and values that are partly still to be developed.

A not exhaustive list of uncertainties that the ethical evaluation of the dynamics of nutrigenomics services and products has to consider comprises at least five types where the first three are mainly cognitive and the last two mainly social and normative. First, experimental, internal, uncertainties we talked earlier about, play a role: genes can have different functions in interaction with their environment and the cause-effect relations are until now mostly unknown. Secondly, in relation to personalized dietary advice based on personal DNA it is unknown how frequent polymorphisms will occur. Will every individual have a certain vulnerability to a certain disease or will it only be applicable to a small group of the population. Third,

uncertainties are formed by risk analysis. Will it be possible to calculate a certain risk of getting a certain condition with a certain lifestyle? In how far can one exclude false positives and false negatives? How difficult will it be to separate the genetic component and the lifestyle component? How high will these risks be? Fourth, for the usefulness of such tests it is uncertain to what extent risk indications about obesity and diabetes and other vulnerabilities really influence people to live healthier and therefore help to prevent these conditions. How will these risks be handled by the actors? Fifth, it is uncertain how nutrigenomics products and services will be developed and used. Will it be possible to develop more effectively health improving products? Or will nutrigenomics be used as a commercial tool?

Experimental Uncertainties

The experimental, internal, uncertainties of nutrigenomics are quite striking. Besides the more "normal" uncertainties of experimenting, like lack of standardization of data and difficulties in establishing causal connections on the base of sound scientific evidence, there are more genomics specific uncertainties. The classical idea of one gene—one protein (Beadle and Tatum 1941) is now abandoned and genes encode a variety of transcripts and proteins (Pearson 2006). Genes can have different functions in interaction with their environment (Piatigorsky 2007). They code for proteins that can have different, even opposing functions. The phenomenon of moon lighting, gene-splicing, or gene-sharing allow proteins to function in distinct modes and makes the road from genotype to phenotype more complex than ever (Sriram et al. 2005). We cannot know for certain how far it ever will be known what the benign or harmful effects of nutrients, foods, or even diets will be. Moreover, many effects, tested on European populations, may not be generalized to other populations (Ng et al. 2009; Easton et al. 2007). Experimental uncertainty can be seen as a cognitive uncertainty, since we do not know what the validity is in relation to nutrients and DNA. This type of uncertainty could affect moral issues concerning tests that indicate lifestyle related diseases in an early stage or tests that indicate susceptibilities to lifestyle related diseases. It also raises questions with regard to the functional food industry and their claims. This cognitive uncertainty may therefore determine moral uncertainty. For example it may trigger questions about what is the right thing to do in relation to moral questions surrounding diagnostic tests or DNA-tests and choices for others.

Uncertainties of Risk Analysis

The second cognitive uncertainty is related to the complexity of nutrient DNA interaction and linked to personalized risk analysis (or diagnostic tests). Risk analysis can be done in two ways. Firstly, an analysis can be done of the susceptibilities that the consumer is running due to certain polymorphisms (Smith et al. 2008). A second way is that biomarkers are identified. By following the dynamics of these biomarkers by measuring mRNA and proteins that are formed after a Western diet, it might be

possible to tell a person is developing lifestyle related conditions in an early still reversible stage. Such biomarkers are as yet not available and their clinical validity and utility are still to be proven (van Ommen et al. 2008; only valid biomarkers that indicate a disease are available see Jaffe et al. 2006).

Both types of risk analysis give rise to several questions regarding the uncertainties. Firstly, in relation to risk analysis based on personal DNA it is unknown how frequent polymorphisms will occur. How high will the risks linked to certain polymorphisms be? Will every individual have a certain vulnerability to a certain disease or will it only be applicable to a small group of the population?

Secondly, how certain will the calculation of risks due to susceptibilities to nutrients be? Will it be possible to calculate a certain risk of getting a certain condition with a certain lifestyle? Or will it be difficult to separate the genetic component and the lifestyle component? What does overall calculation of risks mean, for instance, how to make up your mind if your risk for one vulnerability is 65% and for another 45%? One example of a clear indication that genetic testing might be used to predict the susceptibility to certain diet-related conditions is the current research at obesity. Jeffrey Friedman, one of the pioneers in the obesity research, believes that most of the variance of obesity is due to genetic factors (Friedman 2004). Others like Roth et al. (2004) acknowledge the role of genetic factors but emphasize the importance of other factors such as energy expenditure due to physical activity and of influences during the period in the uterus. Despite these differences in opinion, a lot of research is being done at finding markers that could be tested to predict the vulnerability to obesity and its implied diseases. More recently, Meyre et al. (2005) have found proof that three polymorphisms for the gene that codes for ENPP1 could be a marker for increased risks for obesity and diabetes. According to the BBC news this could be the first step towards a DNA-test for obesity and diabetes (BBC-News 2005). The operative words here are "could be."

Moreover, a fundamental uncertainty that is applicable to diagnostic tests indicating a pre-disease, is that many health vulnerabilities do not develop into full diseases; so their identification with "prediseases" is premature. From daily life the experience of a small illness that is healed by the body is rather common. It is interesting to notice that large scale research in populations show again and again that many people have had strokes or brain damages without recognizing it, and without any later problems (Rutten et al. 2005; Obuchowski et al. 2007; Vernooij et al. 2008). There is quite a lot of chance that a "predisease" won't develop into a disease due to the normal reactions of the body. Finally, the companies that currently offer these tests on the market (internet or elsewhere) are mostly not very reliable. An analysis of the US Government Accountability Office proved that these companies often mislead their customers (Kutz and Government Accountability Office (GOA) 2006; Ng et al. 2009).

Uncertainties of Personalized Dietary Advice

Third, there are uncertainties connected with the preventive measures and dietary advice on the basis of risk analyses. Personalized advice can be based on a DNA test

that might reveal susceptibilities to certain lifestyle related conditions or the earlier mentioned biomarker tests. Will the expectation become reality that genomics produces tailor made recommendations with respect to drugs and food? To what extent may the risks be reduced by adopting a healthy lifestyle or by eating certain products? Also these uncertainties cause moral uncertainty in relation to tests, dietary advice, and the functional food industry. For example, is it right to inform somebody about a high risk without full certainty how it can be reduced? (Rose 1985).

The preventive actions taken to delay certain health risks on the basis of predictive testing are in many cases not fully effective. In the case of osteoporosis, "…preventive measures available to women 'at risk' do not eliminate the risk of adverse outcome" (Hjörleifsson and Schei 2006, p. 897). How will these risks be handled by the actors? Will the consultant or the consultee inform at risk relatives about test results? Or should other persons take up this task? Are they able to give meaning to these risks and these only partly effective preventive measures?

Another possibility could be personalized diets based on biomarkers on DNA level. By measuring mRNA and proteins that are formed after a Western diet and by measuring the dynamics of these markers, it might be possible to tell that a person is developing lifestyle related conditions in an early still reversible stage. Or it might be possible to tell that a person is vulnerable to develop these lifestyle related diseases and therefore should change his or her diet. But, such biomarkers are as yet not available, and their clinical validity and utility are still to be proven.

Social and Moral Uncertainties

A fourth type of uncertainty is formed by the reaction of stakeholders upon knowledge about uncertain risks and uncertain advices and is strongly intertwined with social and moral uncertainty. Firstly, from the point of view of consumers it is important to note that it is quite uncertain how governments, insurance companies, dieticians and general practitioners, food companies, retailers, and others will react to these developments. What regulations will be put in place: will they protect the privacy of consumers and will they improve the quality of nutritional recommendations? Will they make the bio-data banks accessible for all or only for limited purposes? (Castle and Ries 2009). What will telecare and ambient intelligence mean in supplying services? (Falas et al. 2003). Secondly, the reaction of the consumers to the attitude of these stakeholders is unclear. How will end-users react? With respect to the usefulness of (individualized) tests it is uncertain to what extent risk indications about obesity and diabetes and other vulnerabilities really influence people to live healthier and therefore help to prevent these conditions (Komduur et al. 2009). It is interesting to mention that even geneticists themselves confess that they will probably not change their lifestyle when a test gives good indications that they run a risk (Hjörleifsson and Schei 2006). Health behavior of people is determined by a complicated set of many factors that influence the final health behavior. Besides fear for risks, which according to most health behavior model forms an important factor for the eventual health behavior performed, also other

factors like social ones are significant influences. For example people are more inclined to agree with a statement if others in the group endorse this statement as well because they want to conform to the opinion of the group. Norms about how to behave are important factors in this social influence (Lind and Tyler 1988). Thus this cognitive uncertainty is strongly linked to moral uncertainty in relation to what people in the future society think is the right or wrong thing to do. This also causes moral uncertainty about decision making about dietary advice or DNA tests on a personal level.

Uncertainties of Products

Fifth, it is uncertain what nutrigenomics products and services for daily use like food will be developed and how they will be used. For instance, in addition to genetic testing aiming to give advice about lifestyle and nutrition German and Watzke (2004) go one step further and foresee personalized foods. These authors see opportunities for example for people with a predisposition to get food related health problems like lactose intolerance but also for the development of foods that improve characteristics such as cognitive, musical, and artistic performance (enhancement). They predict a future for foods designed for different types of metabolism.

Will it be possible to develop more effectively health improving, disease preventive, and performance enhancing products? Or will nutrigenomics merely be used as a commercial tool? (e.g., Genewatch 2006). There are always free riders that try to get a profit with products that only in name have a health effect and there are enough consumers that are so eager to improve their health situation, that governmental regulations are necessary. Are producers able and willing to use nutrigenomics responsibly as a tool to produce more effective healthy products and will they do this? If genomics will be used as a commercial tool it may become an hype. People will then choose for the products without being able to take full responsibility. This fifth uncertainty is again strongly related to moral uncertainty.

Philosophy of Science and Social Philosophy on Uncertainty

In recent philosophy of science and social philosophy some useful ideas have been developed on how to cope with fundamental uncertainties of science and technology firstly in the epistemological and secondly in the moral sense without expecting them to vanish in the progressive development of science.

Firstly, according to traditional epistemology, knowledge and certainty are intimately linked. You are only allowed (justified) to claim you know something if you also believe it and you are *certain* of it. To be certain you have to have direct proof that it is true (Hospers 1953). Therefore to be uncertain means that one does not have all the knowledge that proves that something is true. However, according to philosophy of science (like the theory of Karl Popper, 1902–1994), conjecturing and the corresponding concept of uncertainty belong to the core of the scientific

enterprise; the community of researchers lives with them by a process of constantly reviewing, by organized criticism and, by developing new theories. Popper reintroduces the term "fallibilism" from the American Pragmatist Charles Peirce (1839–1940), which refers to the search for uncertainties by scientific communities. Cognitive uncertainty is made workable by the social and moral certainty that the scientific community will eliminate in the end false negatives and false positives. Popper also makes the transition to the ethics of uncertainty; he states for example: "Ethics was based upon the ideas of personal knowledge and of the possibility of reaching certainty; and therefore the idea of authority. The new ethics, by contrast, is based upon the idea of objective knowledge and of uncertain knowledge." (Popper 1998, p. 63) Note that according to Popper objective knowledge is knowledge that transgresses the individual person.

Secondly, moral uncertainty in the pre-modern period is as much as possible eliminated due to the fact that ethical frameworks formed by religion, philosophy, and politics were socially imposed on the individuals. People had therefore less room for making their own choices. If one did not adapt to uniform social rules, one was excluded and punished. In the modern period this neglect of uncertainty did not change. Established modern academic and applied ethics mirrors this by its neglect of uncertainty: for instance, in *Encyclopedia of Ethics* one can finds scarcely something about this issue (see Chadwick 1990, a book of 619 pages with uncertainty only eight times mentioned; or Reich 1995, a book of 2950 pages that mentions uncertainty 13 times). However, some recent social philosophers point out that the role of uncertainty today is more complex, due to moral and social factors. The social philosopher Zygmunt Bauman (1995) argues that feelings of uncertainty have increased in the postmodern, twenty first century due to social processes. In the current post-modern society the control by authorities is weakened. Due to more leisure time, growth of material welfare, and expanding social networks people have more room for choices. Therefore the certainty of uniform, fixed, and clear-cut norms is gone. Instead people are compelled to choose among a large range of alternative action schemes and norms, while often the consequences of choices and actions are impossible to foresee. Because of the increasing impact of global networks, one can not expect that all people located in a certain area will act according to the same norms and make the same choices; on the contrary, one can only expect increasing diversity of norms. This creates a lot of uncertainty and to overcome this, people are constantly looking for new stable anchor points that can help them to shape their own life (Bauman 1995).

Bauman's analysis of socially determined uncertainties is closely connected with the very influential social theory of Ulrich Beck (1990) on risk society and scientific and technological uncertainties. He claims that postmodern (he calls them late modern) societies constantly produce new problems that originate in applying modern science, due to its analytical and reductionistic character. The scientific practice in the laboratory of controlling the relevant phenomena and obtaining the relevant knowledge thoroughly depends on how much one can manage to "exclude" all the factors that are not interesting (Hacking 1983). The laboratory activity of scientists includes the effort to construct closed systems *relative* to the theoretical requirement to take some variables and their interactions into account,

which in its turn is chosen according to the relevancy in view of the problem, aim, and interest of the researchers (Radder 2003). These systems are never closed as such and applying the laboratory result outside the laboratory confronts one with the excluded factors, indeed, uncertainties. When scientific results move from the laboratory to society always new problems arise that are subsequently solved with new science, giving rise, however, to new unintended and unanticipated consequences due to the reductionistic character of science. Beck's theory implies that our current society is determined by the search for uncertain knowledge, frequent promises of revelation, demolishing of facts, and the constant discovery of normative disagreements.

How many uncertainties with what intensity can a person bear? According to English sociologist Mary Douglas (1921–2007), persons can only to a certain extent live with uncertainties. In everyday life uncertainty has its limits in people's desire for relative stable relationships and for social cohesion. If Douglas (2001) is right, society is providing the certain anchor point of certainties that allows individuals to tolerate a certain amount of uncertainties. Mary Douglas, in her article "Dealing with uncertainty," asks rhetorically "Where do we humans get our confidence in certain knowledge? The answer is cultural learning. …We create institutions that protect our valued ideas" (Douglas 2001, p. 148). Her reflections on certainty resemble very much the ones of Wittgenstein (1969). He stresses the importance of fundamental certainties that cannot be doubted, or, when doubted, get reactions like: "this person is nuts." He states in *On Certainty*, that the human condition begins with non-doubting: "The game of doubting itself presupposes certainty." (Wittgenstein 1969, Paragraph 115). A doubt requires a ground for itself, i.e., a context we trust. Doubting is only possible because we are absolutely certain of certain basic insights like this is my hand, or it is impossible that I was yesterday on the moon.

However, can social contexts provide such an anchor point for personally experienced uncertainties? Even stable social relationships are continuously changing and new ones are developed, while others are losing their dominance. During some eras people experiment more with new relationships and accept more uncertainties. John Dewey (1859–1952), American pragmatist of the second generation, turns the relationship between certainty and uncertainty in a different light. He concedes that the search for certainty is a dominant feeling. But interestingly, Dewey points out that people pay a particular price for certainty: closure of debate, taboos, correctness, and institutions that try to uphold correct behavior. Dewey refers to the negative effects of this desire for certainty and to the lack of stimulus to learning capabilities and to intellectual progress that it entails. "As long as man was unable by means of the arts of practice to direct the course of events, it was natural for him to seek an emotional substitute; in the absence of actual certainty in the midst of a precarious and hazardous world, men cultivated all sorts of things that would give them the *feeling* of certainty." (Dewey 1960, p. 33). Certainties give birth to all kinds of taboos and biased judgments, but the progress of learning enables human beings to experiment and to live with uncertainties. Dewey is suggesting that as long as the context of humans is full of dangers and induces feelings of uncertainty, they are prone to look for certainty; however, if the

context gives rise to feelings of certainty, individuals can feel more relaxed and give more room to feelings of uncertainty. So, people can strike a balance between social and personal (un)certainties and then they can even become "happy to be uncertain."

Three Implications for an Ethics of Scientific Uncertainties

From both recent philosophy of science and social philosophy it is no wonder that genomics does not eliminate all uncertainties but even produces new uncertainties. Nevertheless, from the point of view of dominant ethics, this situation is very problematic, because the five types of uncertainties (or better, their fundamental resilience) we outlined go against the grain of its most cherished assumptions. Firstly, dominant ethics has not explicitly addressed uncertainties and ways of how to cope with them, because it presupposes stable and fixed conditions, in which principles and norms can be upheld. It more or less presupposes a constant, orderly and enduring universe (Korthals 2008). Secondly, the traditional ethical concepts like "informed choice," "individual responsibility," and "consumer control" (Institute of the Future 2003) are not adequate for ethically dealing with these uncertainties (Chadwick 2002; Burgess 2007). Informed consent presupposes a constant and coherent flow of certain information that one can be informed about and that one can use as a foundation of decisions. Individual responsibility presupposes clear lines of connection between agents, actions, their effects and intentions. And consumer control finally requires a constant and stable personality and social context. When the collective implications of the individual choice for personalized nutrition are so huge, more collective ways of opinion and decision making should be tried in which all stakeholders have to readjust their opinions and interests according to the ongoing discussion. This implies that the ethics of protection of the individual against the apparently mighty powers of state and professionals is not fruitful. More adequate is an ethics of participation in continuous discussion on the intricacies of nutrigenomics.

The building blocks of an ethics of uncertainty that we developed until now along the lines of Popper, Bauman, Beck, Douglas, Wittgenstein, and Dewey, emphasizes the positive role of cognitive uncertainties (Popper), the balance between social and personal context of uncertainties (Popper, Douglas, Wittgenstein), the positive role of living with uncertainties (Bauman, Douglas) and even experimenting with them (Dewey), and the negative role of too much certainties (Dewey). This has three implications that also can be seen as three strategies to cope with uncertainties in general.

Firstly, following Dewey's and the general pragmatist idea of "scratch where it hurts," it is recommendable to look for a *selection of uncertainties* that we should pay attention to. Citizens/consumers need an ethics of dealing with uncertainties in the sense of identifying and selecting between important, unbearable ones and less relevant, bearable, ones. There are no general tools or general guidelines to deal with that process of selection, but there are general procedures like consultations, deliberations, and exchange of stories and life narratives. The main thing here is to

find out commonalities and particularities in your own life and that of other affected ones. Some ethical support can be given by Putnam's distinction between common sense doubt, meaning the selecting of more and less certain cases, and philosophical doubt, i.e., the radical denial of all certainties (1995, 57–81):

> We have to remind ourselves of the distinction between common sense doubt and philosophical doubt. Finishing in believing in something is not really a human possibility. Criticism can not be a reason for universal scepsis. The fact that sometimes we are wrong is not a reason to really doubt every particular conviction. (Putnam 1995, p. 75)

Common sense doubt shifts between different types of doubt that are more or less realistic. The reason that "informed choice" is not a good ethical concept in this context, has to do with the fact that it does not say anything about selecting the more certain and less certain recommendations and the incorporation of well-established health considerations into one's diet and personal health. We need ethical categories that assist consumers in making these selections, i.e., we need categories of consultation and deliberation, and learning processes in which consumers can bring in their life stories (narrative input) and can be assisted to become robust vis-à-vis the health problems that run against their own interests. This ethics of cooperation, dialogue, and of sharing life experiences between consumers and professionals implies that consumer groups should try to bridge the gap between production and consumption of food and new technologies and to incorporate the new health considerations into their food style together with the main stakeholders like governments and food industry.

Secondly, in accordance with the pragmatist ethics earlier developed (Keulartz et al. 2004; Korthals 2008), it is ethically desirable to explore the uncertainties, paradoxes, and various scenarios in *debates* that are organized on the basis of the Jamesian and Deweyian idea of inclusion: "The course of history is nothing but the story of men's struggles from one generation to generation to find the more and more inclusive order. *Invent some manner* of realizing your own ideals which also satisfy the alien demands, that and that only is the path of peace!" (James 1897, p. 205)

Debates are to be organized not because it is the core of democracy to talk, but because only so all relevant viewpoints and interests vis-à-vis an issue get heard, and can be commented upon, and contribute to the meaning frames that in the end stand behind the political decisions that elected politicians have to make. Not for the sake of reaching consensus and of making a decision are debates organized, but to contribute to this collective process of making up your own mind. The scenarios comprise (un)desirable possibilities, not always plausible future plans, and they are made to find out what impact a certain possibility can have (Peterson et al. 2003).

Thirdly, to strike the balance between the social and the personal level, one should also pay attention to Dewey's idea of "*happy with uncertainties*." How to become happy with uncertainties? Again some philosophers have given here some clue. There are several possible strategies and probably a balanced mix of all is often the best choice. One can tackle uncertainty by denying being at risk, and just

go on with living and preventing being reminded of the unpleasant signals that bring to mind that one is confronted with uncertain risks. The alternative is that one confronts oneself with being at risk and tries to prevent as much as possible the early stages of the diseases (of course, there is a kind of middle road as well).

There is also the possibility that one is informed about being at risks without any available therapies, as we discussed earlier. Here one can choose between confronting the uncertainty with strong emotions that induce people to forget their present state of the body. This is the line of Spinoza's *Ethics*: suppressing feelings of anxiety by other feelings, for instance by feelings of enjoyment while eating good food, instead of constantly worrying about your own health when you eat something. Or one can try to reason and to sublimate the anxiety feelings by having better thoughts. This is in line with Aristotle's *Nicomachean Ethics*. According to him, you take into account the broader meaning of feeling good for your own health, and you relativize smaller, short term evils.

Dewey again would stress that inquiry can make one happier in living with fundamental uncertainties. Inquiring with others in finding which new lifestyles, products, and tastes are more ethically desirable is something like a (moral) inquiry. In this case you are pushing the frontiers of your taste in new, uncertain fields without feeling unhappy. The balance of certainties and uncertainties is dependent on the relations between individual and context.

Co-Production of Genomics and an Ethics of Uncertainty

These three implied strategies (selection, debates, and happy with uncertainties) can be made fruitful for our original questions: How to live as an interested citizen/consumer with uncertainties, ambiguities, and paradoxes of genomics? How to tackle the five types of uncertainties? These different strategies of coping with uncertainties are an alternative to traditional ethical strategies of analyzing and emphasizing the role of informed consent and individual responsibilities in these situations.

First, *selection* covers sorting out the hypes from the truth and assessing different types of uncertainties from the more to the less reliable ones. How can the citizen/consumer know what are the hypes and what are the real, troubling, uncertainties? As we have seen, a science like nutrigenomics does not have a directly applicable sieve for truth, in particular for the very complex issues we discussed with regard to the five types of uncertainties. But also society has not a sieve for the truth of certain knowledge and should allow some room for uncertainty. Moreover, the cognitive uncertainties about the connections between foodstuffs, genes, and their effects are intrinsically connected with the normative ones. Claims about the health effects of certain foodstuffs, or claims about the possibility to prevent or postpone a certain disease mix up cognitive and normative claims. What claims are reliable and what not? In how far can private companies be trusted? These questions confront the patients and consumers with the question: Whom to trust? Establishing trustful relations between nutrigenomics, producers, and its end-users is therefore a requirement.

Secondly, in concrete *debates* and consultations one can identify the opportunities for new forms of cooperation by co-managing technological alternatives and selecting ethically desirable alternatives out of the possible scenarios. Living a good life in a world with genomics products and services like high tech food and drugs, implies the deployment of procedural and substantive aspects of deliberations. Deliberations require fair procedures of participation and agenda setting. They also ask for some substantive normative orientation like the values of living and cooperating. Embedding high tech technologies in daily life should mean connecting them with social interactions of peaceful and meaningful actors. Scenarios can be very helpful in imagining future possibilities and future moralities.

Thirdly, in trying to *live happily with uncertainties*, we assume that we can afford some uncertainties with respect to our health and body. But how much can we afford? It is not an easy thing, because the uncertainties do not only comprise the relation between food and genes. They also indicate that the exact boundaries between food and drugs and between health and disease are to be rewritten. Consumers have to cope with new gray zones between food and medicine. As Hippocrates' adage "let food be your medicine" shows, there have always been unclear and sometimes fussy boundaries between the two, but because of the new opportunity of prevention based on nutrient DNA interaction there is now a new situation (Korthals 2007). As Foucault makes clear in his history of sexuality, the adage of Hippocrates was never meant as a recommendation to let health be the only value of your life and to try to prevent risks as much as possible (Foucault 1998). Foucault contrasts the dietetic method of living with one's fate with the therapeutic method of trying to prevent diseases against all costs. With respect to health the dietetic method of living would mean that as long as we are experiencing the certainty that we are healthy, we have no reason to fear having a risk for a disease.

More concretely with respect to the first type of uncertainty: Suppose that it indeed is structurally the case that foodstuffs have multiple effects on the body, that the boundaries between health and disease are unclear, and that indeed genes can have different (for humans positive and adverse) functions in interaction with their environment. In this case, reflections on individual responsibilities with respect to certain vulnerabilities people might have and how people with these vulnerabilities should act, do not have priority because it is possible that the supposed polymorphisms produce not only vulnerabilities, but also produce opportunities in the medical sense, of preventing against certain diseases, and in the non-medical sense, of being challenges. Moreover, the kind of health system people choose produces a different social environment and consequently elicits different functions of genes depending on that environment. Scenario building in the sense of imagining these different environments with different relationship to genes can be illuminating in finding the moral sensibilities. The ethical question for many individuals is therefore what type of health systems according to which genomics innovations, products, and services should be developed.

With respect to the second type of uncertainty, for instance about how frequent polymorphisms that determine certain vulnerabilities, will occur, this issue will be used by some individuals or groups either to deny that they have these risks and for others to affirm these because they think it is in their advantage. In the third and

fourth case of uncertainty, different scenarios with types of governance of genomics products and services can elicit different moral sensibilities and make deliberative participants aware of the morally relevant issues. The fifth uncertainty concerning the use of genomics to develop more effectively health improving products or as a purely marketing tool, will be definitely solved in the last direction when consumers and governments do not pay attention to this last possibility and develop an institutional framework for integer and transparent health claims.

The types of uncertainties can be made more bearable by developing future stories or scenarios involving different genomic developments. Imaginary futures constructed by artists can be helpful as well. Last but not least, deliberations between professionals and patients/consumers/citizen are needed to find out the balance of certainty and uncertainty people can live with. Or to say the same thing differently, to sort out in a deliberative way uncertainties that are relevant and ones that are of minor importance and look only relevant. The American pragmatist John Dewey called those deliberations "dramatic rehearsals" (Keulartz et al. 2004; McVea 2007).

These strategies with regard to the uncertainties of nutrigenomics contribute to what since Jasanoff (2004) is called the co-production of science and society: "*co-production is the simultaneous production of knowledge and social order.*" (p. 5) Jasanoff makes it clear that producing technologies means addressing and resolving problems of nature and problems of society. Technologies embody natural and social concepts and strategies, which implies that they differ according to choices people make about how to live with technologies. Living happily with uncertain technologies is possible on the basis of co-production.

What Implications Does This Have for Consumers and Their Social Context?

In this section we will concentrate on the implications for consumers; however, they are not to be conceived independently of any context, so we will also discuss the main agencies acting in this context although only with respect to their relationship with consumers.

Firstly, citizen/consumers could consider not taking part in the genomics products and services network. But it is not easy to get rid of nutrigenomics and refrain from applying it to obesity. In an age of massive intellectual, economic, and political investment in genomics, of a fundamental mismatch between foods offered and lifestyles and health profiles, this would not be the best thing to do. What to eat in the new situation of living a long life under dominantly sedentary circumstances? How to reestablish a fit between our bodies and the world? It seems that consumer/citizens are in need of nutrigenomics for fine-tuning food in newly emerging lifestyles. With these new, mostly sedentary lifestyles, one simply does not know what is healthy to eat. Traditional recipes of what to eat are connected with lifestyles that cover a lot of physical labor, contrary to the present ones. Secondly, with respect to the strategy of selection, what the consumer needs is to get assistance in selecting the important from the unimportant uncertainties and products and

services. This would firstly imply new institutions for education, consultations, and deliberations; secondly, producers and consumer groups should bridge the gap between production and consumption. Thirdly, consumers could ask the government for transparent and relevant regulations of health or quasi health claims (like "light") that comprise the whole product, and not certain ingredients. Finally, consumers could ask the government for assistance in finding out the origin and quality of foodstuffs, with the aim of better participating and organizing contributions to public debates. This connects with the special status that consumer groups have; according to a recent Eurobarometer finding, they are in the food sector the most trusted source (33%).

In the context of consumers other stakeholders play a role. Governments and their agencies, scientists, and technologists, and companies working in the field of genomics can in several ways assist consumers to live happily with uncertainties. *Governments* can assist consumers by organizing the research agenda of nutrigenomics in a democratic way, not exclusively oriented towards personalized nutrition, but oriented towards the prevention of common illnesses, common conditions, and chronic diseases. There is a role to play for public health nutrigenomics, directed at general risk profiles. Governments should regulate the three sectors, food, drugs, and the new emerging grey zone, improve research ethics and medical testing of health foods, and allow only affordable health foods. Its main policy aim in nutrition policy should be the encouragement of the (in)formal ties by pleasurable eating. Health should be a secondary goal in eating (Korthals 2004) and consumer groups should be empowered as stakeholders and be given a voice not only downstream nutrigenomics (with respect to the final products) but also upstream the nutrigenomics research agenda. To tackle the issue of easy consumers' vulnerabilities to expectations and hypes, it is necessary to establish independent gatekeepers to safeguard the independency of testing, marketing, communicating, and providing the services of nutrigenomics. Trust of citizen-consumers in the food and health sector can best maintained by the establishment and maintenance of independent bodies of fixing and monitoring rules with respect to health and enhancement claims.

For *genomics researchers* assisting consumers these considerations would firstly imply that more attention is paid to research ethics and professional ethics, like in medical research. No publication should be considered in case of immature or in case of provocative but irreproducible/invalid research. Secondly, publication of research on a tiny detail without context outside scientific circles should be prevented; the inherent complexity of nutrigenomics research implies that tiny detail research results should only be published in connection with the larger context. Thirdly, the huge complexities of the interactions between genome, genetic profiles, and environments, like diets and lifestyles reduces severely the possibility of reproducing experiments in other locations and with other populations, because food and lifestyles differ so much and are impossible to exclude (Sinha 2005). Genomics is not about a single relationship between one single gene and its expression, but about the reactive genome, contextualizing on all levels. Food has multiple effects on the genetic profile, and is dependent on the food choices that again are influenced by lifestyle factors and ethnic diversity. It means that validation

and falsification of causal relationships are confronted with extremely difficult and expensive research designs. One implication is that there is a good chance for fake claims and unrealistic expectations, of which the consumers have to be (made) aware by critical nutrigenomics researchers. Finally, conflicts of interests should be prevented. In general, scientists should not refrain from complex issues but try to communicate to the public the complexities (Hjörleifsson and Schei 2006). Due to the fact that there is indeed a slight case for developing personalized nutrition, the exact proportion between research for public health and for personalized nutrition should be subject of public debate in which scientific input is urgently needed. The research focusing on common illnesses should not come into disarray, as the one for affordable and common drugs and foodstuffs. Making healthy foodstuffs easy to get for everyone remains an important challenge for nutrigenomics.

Nutrigenomics-producers acting according to Corporate Social Responsibility codes can give consumers some assistance in deciphering marketing slogans and claims. Secondly, companies should concentrate on common illnesses that are relatively easy to cure. Thirdly, public health measures should have priority above personalized care for a few. This implies also that the products and services should be affordable products. It requires that healthy food is made easy available and affordable. Thirdly, companies have a lot to win from cooperation with networks of consumer groups.

As we have seen, the complex relationship between food and genetic profile allows for various reactions of the body on food, sometimes positive, sometimes negative. Genes influence the expression of other genes in proteins and the organism and vice versa so the genome is not one, stable, all determining command post. Moreover, traditional truths on healthy foodstuffs, like wine, chocolate, vegetable oils, and milk, collapse. For some wine is healthy, for some it is not; first all vegetable oils were seen as healthy, later not, etc. Still, we need serious research, i.e., validated results of nutrigenomics for fine-tuning food in lifestyles, although it will be difficult, because of these uncertainties and ambiguities, to incorporate the aspirations and results of nutrigenomics in our daily life, in adequate policy measures, and in ethically acceptable research agendas.

Future Prospects and Conclusion

Granted that indeed there is a role to play for personalized nutrition oriented towards health, one is faced with particular ethical issues in connection with the scientific peculiarities of nutrigenomics. Genomics' applications have an uncertain future; cognitive and normative uncertainties galore and "mistakes" and fundamental uncertainties are inevitable. A lot depends on the interaction between research developments, research priorities, prospects for profits and ethical concerns. It is unmistakably the case that a more personal appeal to customers of food and medicine to incorporate recent health standards into their food styles can have some effect. From this perspective, it seems ethically desirable that citizens/consumers learn to cope with the hypes, the (fundamental and relative) uncertainties of this new approach. They have to learn to deal with the most important

(un)certainties, which means that they have to shift the more important from the less important uncertainties. This implies not only room for informed choice, but also for consultations and deliberations on these uncertainties. Complementarily, from a public health point of view, the potentialities of nutrigenomics in improving the health of the population, in particular of the least well off, should be developed as well. This implies for governments that in certain areas they have to make tough decisions, like making clear distinctions between food, medicine, and a grey zone and subsequently doing a lot of regulatory work for this grey zone. Moreover, consultation is necessary with the public. Thirdly, governments should oversee that public health research and care should remain the most important share of the research agenda for nutrigenomics. Finally, the public should be involved in deliberating on upstream nutrigenomics development, not only downstream the services, products, and Biobanks (Burgess 2007). All in all, individualized nutrition needs strong government. In situations of fundamental uncertainty, one is in need of mapping different arrangements of the interaction between genomics and societal developments. This requires non-traditional ethical perspectives, like deliberations, imaginary futures by aesthetic explorations, future explorations by scenarios of different moral screenplays, and dramatic rehearsals. Notions of consumer control and of informed consent are rather helpless in these situations.

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References

Aggett, P. J., et al. (2005). PASSCLAIM, process for the assessment of scientific support for claims on foods. *European Journal of Nutrition, 44*, 1–2.

Amendola, A. (2002). Recent paradigms for risk informed decision making. *Safety Science, 40*(1–4), 17–30.

Bauman, Z. (1995). *Life in fragments: Essays in postmodern reality*. Oxford: Blackwell.

BBC-News (2005, June 17). DNA test for diabetes and obesity. *BBC Health*. London: BBC.

Beadle, G. W., & Tatum, E. L. (1941). Genetic control of biochemical reactions in neurospora. In *Proceedings of the National Academy of Sciences of the United States of America, 27*(11), 499–506.

Beck, U. (1990). *Risk society*. London: Sage.

Brown, N., & Michael, M. (2003). A sociology of expectations: Retrospecting prospects and prospecting retrospects. *Technology Analysis and Strategic Management: 15*(1), 3–18.

Bryson, B. (2003). *A short history of nearly everything*. London: Black Swan.

Burgess, M. (2007). Proposing modesty for informed consent. *Social Science and Medicine, 65*(11), 2284–2295.

Castle, D., & Ries, N. (Eds.). (2009). *Nutrition and genomics*. Amsterdam: Academic Press.

Chadwick, R. (Ed.). (1990). *Encyclopaedia of applied ethics*. New York: Academic Press.

Chadwick, R. (2002). Nutrigenomics, individualism and public health. *Proceedings of the Nutrition Society, 63*(1), 161–166.

Davis, C. D., & Milner, J. (2004). Frontiers in nutrigenomics, proteomics, metabolomics and cancer prevention. *Mutation Research, 551*, 51–64.
Dewey, J. (1960). *The quest for certainty*. New York: Putnam.
Douglas, M. (2001). Dealing with uncertainty. *Ethical Perspectives, 8*, 145–155.
Easton, D. F., et al. (2007). A systematic genetic assessment of 1, 433 sequence variants of unknown clinical significance in the BRCA1 and BRCA2 breast cancer–predisposition genes. *American Journal of Human Genetics, 81*, 873–883.
Falas, T., Papadopoulos, G., & Stafylopatis, A. (2003). A review of decision support systems in telecare. *Journal of Medical Systems, 27*(4), 347–356.
Foucault, M. (1998). *History of sexuality* (Vol. 2). London: Penguin.
Friedman, J. F. (2004). Modern science versus the stigma of obesity. *Nature Medicine, 10*, 563–569.
Fukuyama, F. (2002). *Our Posthuman Future: Consequences of the Biotechnology Revolution*. New York: Farrar, Straus and Giroux.
Genewatch UK. (2006). *Your diet tailored to your genes: Preventing diseases or misleading marketing?*. Buxton: Genewatch UK.
German, J. B., & Watzke, H. J. (2004). Personalizing foods for health and delight. *Comprehensive Reviews in Food Science and Food Safety, 3*, 145–151.
Gottweis, H. (2005). Governing genomics in the 21st century: Between risk and uncertainty. *New Genetics and society, 24*(2), 175–194.
Hacking, I. (1983). *Representing and intervening*. Cambridge: Cambridge University Press.
Hjörleifsson, S., & Schei, E. (2006). Scientific rationality, uncertainty and the governance of human genetics: An interview study with researchers at deCODE genetics. *European Journal of Human Genetics, 14*(7), 802–808.
Hospers, J. (1953). *An introduction to philosophical analysis* (2nd ed.). London: Prentice-Hall.
Institute of the Future (2003) *From nutrigenomic science to personalized nutrition*. http://www.iftf.org/files/deliverables/SR-793_NCNG_Pers_Nutri.pdf
Jaffe, A. S., Babuin, L., & Apple, F. S. (2006). Biomarkers in acute cardiac disease: The present and the future. *Journal of the American College of Cardiology, 48*(1), 1–11.
Jasanoff, S. (2004). *States of knowledge: The co-production of science and the social order*. London: Routledge.
Jasanoff, S. (2005). In the democracies of DNA: Ontological uncertainty and political order in three states. *New Genetics and Society, 24*(2), 139–156.
Katan, M. (2004). Health claims for functional foods. *British Medical Journal, 328*, 180–181.
Keulartz, J., Korthals, M., Schermer, M., & Swierstra, T. (2004). Ethics in a technological culture. A programmatic proposal for a pragmatist approach. *Science, Technology and Human Values, 29*(1), 3–30.
Komduur, R. H., Korthalsm, M., & Te Molder, H. (2009). The good life: Living for health and a life without risks? On a prominent script of nutrigenomics. *British Journal of Nutrition, 101*(3), 307–317. doi:10.1017/S0007114508076253.
Korthals, M. (2004). *Before dinner*. Dordrecht: Springer.
Korthals, M. (2007). Ethics of personalized nutrition (Chap. 12). In K. Frans, B. Laura, & D. Frank (Eds.), *Personalized nutrition: Principles and applications* (pp. 221–235). London: Taylor and Francis.
Korthals, M. (2008). Ethical rooms for maneuver and their prospects vis-à-vis the current ethical food policies in Europe. *Journal of Agricultural and Environmental Ethics, 21*, 249–273.
Kuhn, T. H. (1962). *The structure of scientific revolutions*. Chicago: University of Chicago Press.
Kutz, G., & Government Accountability Office (GOA). (2006). *Nutrigenetic testing: Testimony before the special committee on aging*. Washington, DC: U.S. Senate. (GAO-06-977T).
Lind, E. A., & Tyler, T. R. (1988). *The social psychology of procedural justice*. Berlin: Springer.
McVea, J. F. (2007). Constructing good decisions in ethically charged situations: The role of dramatic rehearsal. *Journal of Business Ethics, 70*, 375–390.
Merton, (1968). *Science and the social order, in: Idem, social theory and social structure*. New York: The Free Press.
Meyre, D., Bouatia-Naji, N., Tounian, A., Samson, C., Lecoeur, C., Vatin, V., et al. (2005). Variants of ENPP1 are associated with childhood and adult obesity and increase the risk of glucose intolerance and type 2 diabetes. *Nature Genetics, 37*, 863–8667.
Ng, P. C., Murray, S. S., Levy, S., & Venter, J. C. (2009). An agenda for personalized medicine. *Nature, 461*, 724–726.

Obuchowski, D., Holden, M., Modic, G., Cheah, A., Fu, M., Brant-Zawadzki, R., et al. (2007). Total-body screening: Preliminary results of a pilot randomized controlled trial. *Journal of the American College of Radiology, 4*(9), 604–611.

Pearson, H. (2006). Genetics: What is a gene. *Nature, 441*, 398–401.

Peterson, G. D., Cumming, G. S., & Carpenter, S. R. (2003). Scenario planning: A tool for conservation in an uncertain world. *Conservation Biology, 17*, 358–366.

Piatigorsky, J. (2007). *Gene sharing and evolution*. Cambridge, MA: Harvard University Press. USA.

Pinch, T. (2000). The golem: Uncertainty and communicating science. *Science and Engineering Ethics, 6*, 511–523.

Popper, K. (1998). *The world of parmenides: Essays on the pre-socratic enlightenment*. London: Routledge.

Putnam, H. (1995). *Pragmatism: An open question*. Oxford: Blackwell.

Radder, H. (Ed.). (2003). *The philosophy of experimentation*. Dordrecht: Springer.

Reich, W. T. (1995). *Encyclopedia of bioethics (5 Volumes)* (2nd ed.). New York: Simon & Schuster Macmillan.

Rose, G. (1985). Sick individuals and sick populations. *International Journal of Epidemiology, 14*, 32–38.

Roth, J., Qiang, X., Marbán, S. L., Redelt, H., & Lowell, B. C. (2004). The obesity pandemic: Where have we been and where are we going? *Obesity Research, 12*, 88S–100S.

Rutten, F., et al. (2005). Unrecognized heart failure in elderly patients with stable chronic obstructive pulmonary disease. *European Heart Journal, 26*, 1887–1894.

Sinha, G. (2005). News feature: Designer diets. *Nature Medicine, 11*, 701–702.

Smith, G. (2005). *The genomics age—how DNA technology is transforming the way we live and who we are*. New York: Amacom.

Smith, A. D., Kim, Y.-I., & Refsum, H. (2008). Is folic acid good for everyone? *American Journal of Clinical Nutrition, 87*(3), 517–533.

Sriram, G., Martinez, J., McCabe, E., Liao, J., & Dipple, K. (2005). Single-gene disorders: What role could moonlighting enzymes play? *The American Journal of Human Genetics, 76*(6), 911–924.

Stephenson, F. (2008). *DNA, how the biotech revolution is changing the way we fight disease*. Amherst: Promotheus.

van Ommen, B., et al. (2008). The challenges for molecular nutrition research 2: Quantification of the nutritional phenotype. *Genes & Nutrition, 3*(2), 51–59.

Van Roost, M. (2005). The metabolic syndrome: A ticking time bomb. *Food Engineering and Ingredients, 30*(2), 5–7.

Vernooij, M., et al. (2008). Prevalence and risk factors of cerebral microbleeds. *Neurology, 70*, 1208–1214.

Wittgenstein, L. (1969) On certainty. In G. E. M. Anscombe & G. H. von Wright (Eds.), (D. Paul & G. E. M. Anscombe, Trans.). Oxford: Blackwell.