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The Concept of Personalized Nutrition in Benin as Example for Developing Countries

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Abstract

Personalized nutrition (PN) collects and analyses individual data iteratively to generate dietary advice tailored to the characteristics of a person. While PN is mainly discussed in the context of Nutrigenetics and non-communicable diseases in developed countries with excessive food supply, this paper contrasts this scenario to one of unequal or short food supply, as found in developing countries. To overcome under-nutrition and avoid untargeted countrywide distributions of supplements, PN could identify individual deficiencies and target these by recommending specific locally available food items. As PN aims at a balanced diet, it simultaneously targets deficient as well as excessive intakes. This might additionally decelerate the prevalence of double burden of malnutrition in developing countries in the course of nutrition transition.

Keywords

Personalized nutrition; Developing countries; Nutrition transition; Double burden

Abbreviations: NCD: Non-Communicable Diseases; PN: Personalized Nutrition; DBS: Dried Blood Spots.

Introduction

For the last decades, agricultural production, processing and storage of food items, as well as infrastructure, mechanization and urbanization have been enhanced significantly around the world [1]. Consequently, a growing part of the world population faces a continuous abundant food supply, not only in high-income countries, but also in urbanized areas of middle- and low-income countries. This includes many regions in Africa, where the so-called nutrition transition takes place; a shift in the composition of diets towards increased intakes of saturated fat and sugar, and decreased intakes of fiber [2-5]. Unfortunately, such circumstances not only resulted in a decrease in under-nutrition and related diseases. Worldwide, the prevalence rates of formerly rare conditions such as overweight, elevated blood pressure, hyperglycemia and dyslipidemia have been rising contemporaneously, with currently 1.9 billion adults and 41 million children under 5 years being overweight [6,7]. These parameters may lead to chronic non-communicable diseases (NCD) which have been related to 71% of global deaths. It was estimated that each year 17.7 million people die of cardiovascular diseases, i.e. 43% of the total NCD deaths, 8.8 million of cancer (22%), 3.9 million of respiratory diseases (10%), and 1.6 million of diabetes mellitus (4%) [8]. 75% of the global deaths occur in low- and middle-income countries [7], and it is discussed that nutrition transition as well as social status influence the incidence of cardiovascular diseases and cancer [9,10]. In the West African Republic of Benin the adults' prevalence of obesity rose from 6% in 2008 to 9.6% in 2016 [11]. The prevalence of diabetes was about 5.1% in 2016 [12], and there are already projects to reduce the incidence of diabetes, as well as to reduce the prevalence of its risk factors [13]. Additionally, Benin established a population-based cancer registry in 2014 to monitor cancer incidences [14]. The global burden of NCDs affects not only the subjective well-being; it also contributes substantially to the rise in health care costs. In 2010 for instance, they amounted to 500 billion US$ for the treatment of diabetes and to 863 billion US$ for cardiovascular diseases. By the year 2030, these costs were estimated to make 745 and 1,044 billion US$, respectively [15].

Nevertheless, 462 million adults are still underweight, 155 million children are stunted, and 45% of deaths among children below the age of 6 years are associated with under-nutrition worldwide [6,16]. In Benin, food insecurity still affected about 11% of the population and 34% have limited or poor food consumption in 2013 [17]. Additionally, in 2013, Benin had the third highest hidden hunger index out of 149 countries after Niger and Kenya [18].

This relatively new phenomenon of a "coexistence of under-nutrition along with overweight, obesity or diet-related NCDs, within individuals, households and populations, and across the life-course" was defined by the World Health Organization as "Double burden of malnutrition" [16]. An obese individual with nutritional anemia serves as example for an individual double burden of disease, while an overweight mother with a stunted child is a typical example of a household double burden. Thus in 2016, the United Nations General Assembly declared the years 2016 to 2025 as the "United Nations Decade of Action on Nutrition". Among others, it called for providing nutrition-related education for everyone, to enhance the worldwide knowledge of a healthy lifestyle and prevent the increase of diet-related diseases and costs [6].

General Advice for a Healthy Diet

The idea to provide information on nutrition and give dietary advice to prevent nutrition related diseases already started centuries ago. In the 15th century, for example, the adventurer Jacques Cartier described "scurvy", a disease due to ascorbic acid deficiency. He discovered that consuming "Anneda tree extract" cured and prevented scurvy and developed a general recommendation for ships' crews to consume Anneda tree beverages [19]. In the following centuries, further deficiencies of food residues were discovered to cause specific diseases and over time, dietary recommendations were extended and specified.

Nowadays, dietary guidelines are omnipresent and provide easy-to-understand advice for consumers on how to achieve and maintain a healthy lifestyle. They are distributed by transnational organizations, such as the "10 tips for healthy eating" of the European

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Food Information Council [20], but also on country-level, such as the "10 Regeln der DGE" published by the German Nutrition Society in Europe [21], or the "Guide alimentaire" by the nutritional counsil of Benin in West Africa [22]. The guidelines are quite similar; however, country specific guidelines put general recommendations into the local context to increase their populations' comprehension and compliance. Benin for instance provides a visualization of food groups to be consumed as traditional roundhouse with a thatch roof. The food items within the five groups are largely local products, like yam, cassava or Amiwo. The glass and a water bottle at the entrance symbolize Benin's hospitality and serves as reminder to drink water throughout the whole day (Figure 1).

The burden of NCDs has been rising continuously, despite the widespread availability of plain and locally adapted dietary advice. This raises the question: why do people not follow the guidelines to improve their own health? The food industry follows the innate human demands, e.g. for sweet and fatty food items [2], and lifestyle magazines sell by various claims on healthy nutrition. Additionally to this cacophony of partly conflicting information, general guidelines on a healthy lifestyle do not necessarily stimulate changes. In a meta-analysis of 29 studies, for example, only a weak positive association was found on the relationship of nutritional knowledge and dietary intake [23]. Increasing efforts to promote generic dietary advice might thus only have minor effects on dietary transition and a subsequent decrease in NCDs.

Personalized Nutrition

Personalized nutrition (PN) tailors dietary advice to the individual requirements and preferences of a person and is supposed to improve the perceived relevance of a given advice and consequently leads to an increased motivation for changing the dietary behavior towards a healthier lifestyle compared to generic guidelines [24,25]. PN in form of one-on-one attendance by dieticians or physicians has already been existing for several decades [26]. By means of dietary assessment, medical history, and/or phenotypic markers, as blood metabolite levels, an expert develops a personalized dietary plan with specific goals.

Through the worldwide usage of smartphones and applications, the possibility of home-based blood sampling as well as the development of high-through-put technologies to analyze characteristic biomarkers in blood or urine, PN has the opportunity to achieve a new level. PN does not necessarily require expert-conducted manual assessments and analyses anymore, but can use smartphone applications. Here, the analysis of data and feedback development is performed time- and cost-efficiently by implemented algorithms, and the recommendations are available at anytime and anywhere [27]. It is thus applicable for large parts of the population to act as preventative tool, achieving dietary behavior change, before nutrition related-diseases may become manifest. The opportunity for active participation and recognition in social media may also account for a higher effectiveness of personalized advice [28,29]. Additionally, individual feedback to a person's nutritional behavior might also overcome the proposed inability to evaluate one's own diet, as most Europeans believe their diet to be healthy enough [30].

Generally, we determined three consecutive steps to PN: data collection, data evaluation, and feedback generation. Data collection is conducted to determine the current characteristics of an individual.

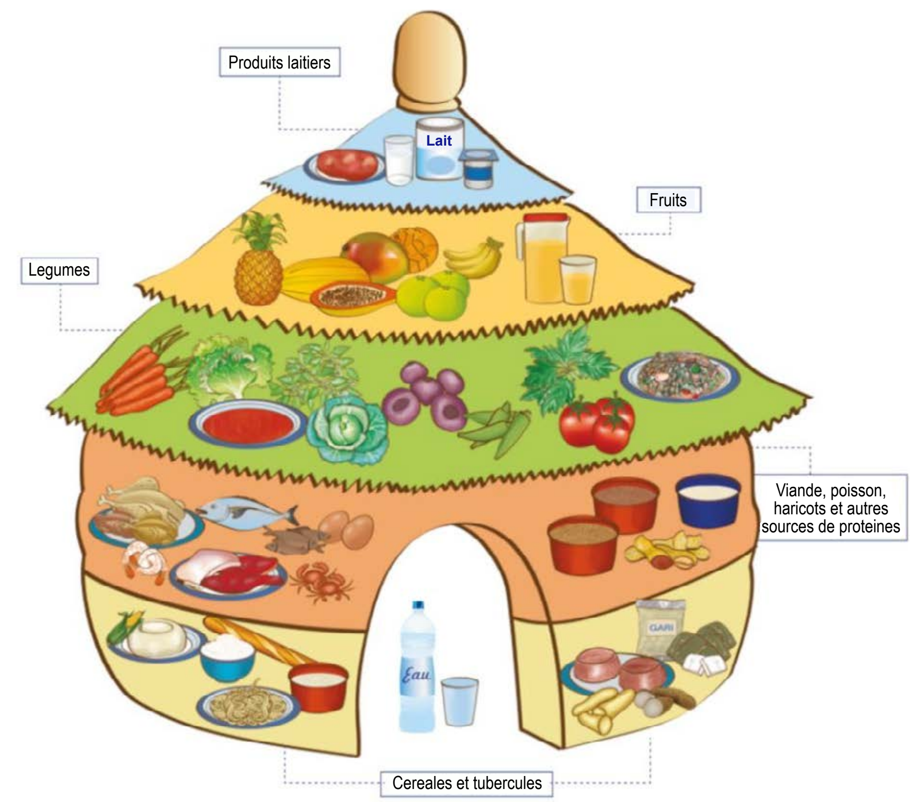

Figure 1: Country specific nutritional guidelines using local food items for visualization: Guide alimentaire, Benin [22].

During data evaluation, the status quo is compared to optimal reference values of the individual. Deviations are rated for example by magnitude and or by predefined rankings. For feedback generation, characteristics to be changed are described and suggestions for behavior changes are given in form of recommendations concerning nutrients, food items or recipes. These steps are iteratively accomplished, and with each cycle, the individual can further approach his/her individual optimal pattern (Figure 2).

Data collection

We divided the data collection for PN into two parts; i.e. data based on phenotype and genotype, respectively. The phenotype describes observable characteristics, for example the behavior of a person; which includes individual dietary intake, physical activity, and anatomy including anthropometry, as well as biomedical or physiological properties. The genotype is the genetic constitution of a person. Based on these data, the risk for certain diseases can be estimated and opportunities on how to change which characteristics towards a healthier phenotype can be indicated. The data or sample collection might require particular expertise (e.g. bioelectrical impedance analysis for estimating body composition), but often studies aim at measurement approaches that are independent of any professional assistance.

To estimate dietary intake, pro- and retrospective assessment tools have been developed. Widely accepted assessment methods are for example the retrospective 24-hour recalls and food frequency questionnaires. Modern technology facilitates dietary assessment and offers the opportunity for immediate data analysis. Besides the digitalization of formally handwritten questionnaires, more objective assessment tools like photos [27,31] or micro-cameras [32] might increase accuracy, especially in terms of portion size estimation and minimize costs and time. Such tools, however, need additional development and testing concerning validity and usability [33]. Most of the dietary assessment tools aim eventually at assessing not only the intake of food items, but of nutrients. The daily nutrient intake can be calculated using a food composition database, which lists relevant food items of the questionnaires or photos, and additionally comprise precise values of the nutrient content.

Next to dietary behavior, physical activity plays a crucial role in developing NCDs. It can be estimated by questionnaires, e.g. Baecke's questionnaire [34], but also by wearable devices, such as physical activity trackers [35]. However, in only a few cases, the validity of accelerometers was scientifically accredited [36,37]. Anthropometric data offer valuable clues on the body composition and nutritional status. Measurements of the height, weight and circumferences using simple scales and tapes are sufficient to determine e.g. the Body Mass Index, a marker to classify under- and overweight [38,39], and the waist circumference, indicating fat distribution [40]. More sophisticated tools exist for home-based self-assessment of further physiological parameters, such as blood pressure, pulse rate or blood oxygen saturation [41,42]. Again, their validity was rarely confirmed, e.g. for certain sphygmomanometers [41,43]. Phenotyping also includes the analysis of blood metabolites. Several parameters reflect various aspects of nutritional status, e.g. plasma glucose, cholesterol, triglycerides, vitamins etc. [44]. Next to the classical venipuncture sampling, the usage of capillary blood sampling, so-called dried blood spots (DBS), becomes more important in epidemiological studies, as sampling does not require medically trained staff [45].

Nutritional advice can also be personalized based on findings of Nutrigenetics, which examines the interaction of diet and genome [46-48]. Buccal cells, home-based collected with commercially available kits, serve as samples for determining the genetic constitution of a person. DNA samples will then be sequenced using e.g. micro arrays or Next Generation Sequencing [48].

Data evaluation

Data evaluation aims at comparing the status quo to the individuals' requirements and preferences. However, it is often not feasible to precisely determine the requirements of an individual; they rather have to be estimated. Thus, the assessed daily nutrient intake is compared to respective dietary recommendations, which are estimations for a nutrient intake covering the requirements of 97.5% of the population. They usually only distinguish between sex and age, as well as breastfeeding and pregnancy [49,50]. The recommendations for nutrients vary from country to country, depending on the scientific evidence and the references taken into account, as well as the updating-processes, there are different recommendations [51-53]. The careful choice of the recommendation database is not only evident for the nutrient intake, but for every marker (anthropometrics, blood values etc.). There exists for example a substantial ethnic variation in the distribution of visceral and subcutaneous fat in the body [54]. A study on blood reference values of laboratories in the U.S. and Africa suggested that each laboratory should determine locally derived reference values for each parameter, due to major differences in blood values due to ethnicity [55].

The evaluation of genetical data is based on the findings of nutrigenetic studies. One example is the protective effect of cruciferous vegetables against lung cancer for null allele carrier of GSTM1 and GSTT1, genes coding for glutathione-S-transferases [56]. Thus, if the genotyping of a person's DNA reveals a null allele for GSTM1, the evaluation of the data would indicate a higher need for cruciferous vegetables.

Depending on the feedback, the deviation between status quo and recommendation of each nutrient or phenotypic value is calculated and weighted. The deviation can be expressed by percent of recommended intake or by classifying into certain groups, such as small, medium or high deviation.

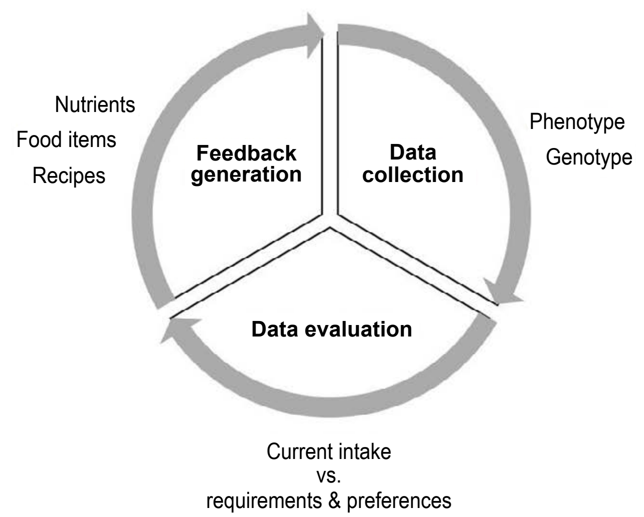

Figure 2: Circle of personalized nutrition.

Feedback generation

Feedback on the data evaluation can be based on foods, recipes or broader lifestyle advice. A human dietary advisor would mentally combine the gathered information and address the most important aspects to be changed. Computerized feedback uses the information of the data evaluation and produces semi-quantitative or quantitative recommendations. Semi-quantitative recommendations mainly aim at reducing or increasing the intake of certain food items or groups. If the intake of a nutrient is higher than the recommended intake, food items with a high content of this nutrient are to be consumed less, and vice versa, e.g. "low carotenoids: eat more carrots; high saturated fat and genetic risk allele: eat less chocolate cream". Quantitative feedback on certain nutrients includes specific quantities of the food items to be consumed e.g. "eat 100 g carrots, pepper or tomatoes per day". A proof-of-principle study on PN showed that focusing on three to four specific markers, e.g. nutrients, anthropometric or blood markers seem to have a substantial effect on behavior change towards a healthier nutrition. During the study they used the semi-quantitative approach, and recommended several food items to be consumed more or less for each target nutrient [24]. For a holistic quantitative feedback, recipes and menu plans can be considered. Mathematical tools like optimizations are able to calculate the optimal combination of recipes to fulfill not only three or four, but all nutritional requirements and can include economic factors or food preferences [57,58].

If more information is requested on why and how to change the diet, texts on all possible target markers, including recommendations on nutrients, food items and lifestyle can be generated using decision trees [59,60]. Pictures or other visualizations might serve as tools to communicate recommendations without the need of a high education level or even literacy, as simple photos of food items with checkmarks or crossed out already point out the desired dietary change. This approach does however not include any kind of explanation or further education.

On a broader view, recommendations based on genetic variants might raise ethical concerns. Certain genetic constitutions were not only linked to diet-related diseases, but also to elevated risks for severe non-dietary related diseases. An example is a single nucleotide polymorphism in ApoE. On the one hand, it is associated with increased LDL-cholesterol and triglyceride levels [61], on the other, also with an elevated risk for developing Alzheimer's disease [62]. Before including genetic-based personalized advice, the associated gene-diet-interaction needs sound scientific evidence for health effects, iterative evaluation of potential psychological effects and the promotion of autonomous choice of each person [63].

Hypotheses on the Application of PN

Excessive food supply

PN was mainly developed for countries with an excessive food supply, both in amounts and variety, as in Europe or North America. It was introduced as a concept to contribute to the reduction of the pandemic dimension of obesity and thus the prevalence of NCDs and their associated health care costs. As the human is evolutionary tailored to save energy, a paradisiac environment where palatable food is omnipresent, also has to be considered as an obesogenic environment. Combined with a sedentary lifestyle and absence of famines, excessive food supply leads to an excessive food intake and promotes obesity. In case of additionally imbalanced food choices, micronutrient deficiencies might be caused, as well (Figure 3, upper part). Even if one intends to follow a healthy diet, a vast quantity of articles, TV magazines or social media entries might also lead to confusion about the "healthiness" of particular food items. The search engine google.com gives over 70 million entries on "healthy eating" (5th Nov. 2018). Additionally, a meta-analysis compared the price difference between healthier and less healthy diet patterns, and concluded that the healthier patterns were more expensive [64]. PN might be able to guide the individuals' food choices towards a healthy but palatable diet, which fulfills the individual requirements (Figure 3, lower part) and increases the awareness of nutrition-related diseases by estimating the personal risks.

Unequal or short food supply

An unequal distribution and/or short supply of food leads to under-nutrition of macro- and/or micronutrients (Figure 4, upper part). The challenge is therefore to adapt the regional food production with available resources to meet the nutritional requirements. Individual, household or community based PN advice might be able to identify specific deficiencies or excesses in macro- and micronutrient intake (Figure 4, middle part). The understanding of these deficiencies and/or excessive intakes as well as personalized recommendations enables individuals and families to react proactively by increasing or decreasing the consumption of locally produced foods. PN may also prevent the prevalence of the double burden of disease, as it generally aims at a balanced diet and is not strictly focusing on nutrient

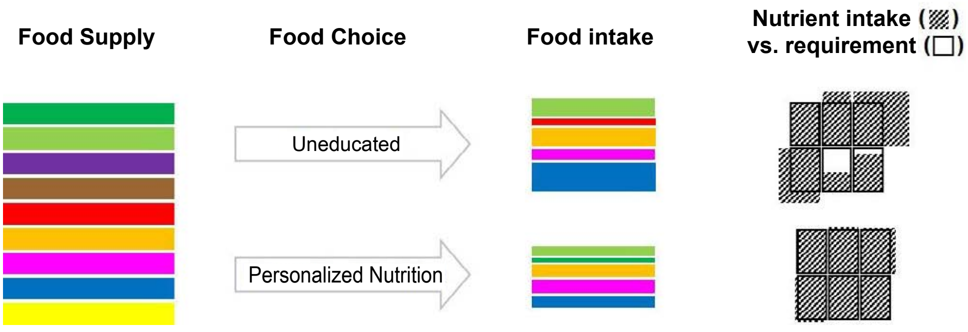

Figure 3: Results of uneducated food choice and Personalized Nutrition on food intake and fulfilment of nutrient requirements in an environment of excessive food supply. Excessive food supply is represented by various colors and large bars. "Uneducated" choice leads to a certain food intake pattern, which mainly exceeds, but does not fulfill all nutritional requirements. "Personalized Nutrition "leads to partly different food intake pattern compared to uneducated choice, which results in a more appropriate approximation of nutrient intake towards the requirements.

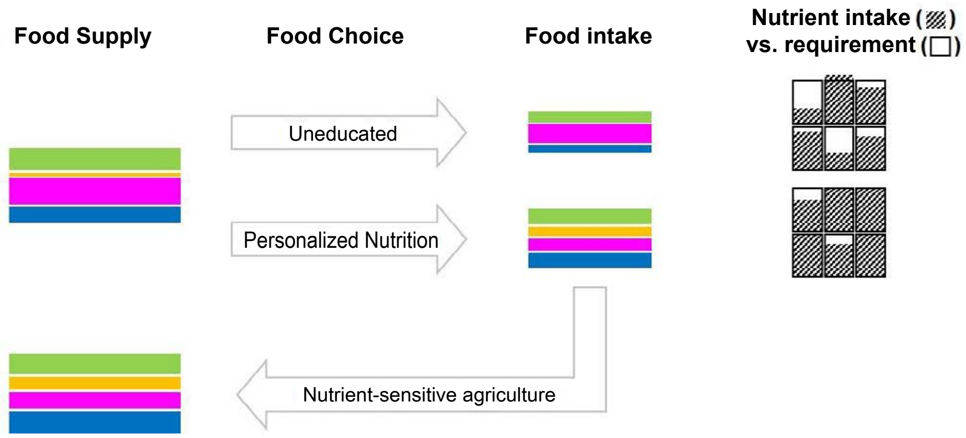

Figure 4: Results of uneducated food choice and Personalized Nutrition on food intake and fulfillment of nutrient requirements in a short food supply environment. Short food supply is represented by few colors and thin bars (compared to Figure 4). "Uneducated" choice leads to a certain food intake, which does not fulfill all nutritional requirements. "Personalized Nutrition" leads to a mainly similar food intake pattern with minor changes compared to uneducated choice, which again leads to a more appropriate approximation of nutrient intake towards the requirements. Nutrient-sensitive agriculture takes place, when the intake and/or demand lead to a correspondent change in agricultural production.

deficiencies. The recognition of the nutritional value of food items, the knowledge about healthy nutrition, and the benefits caused by a large food variety may thus lead to a shift in the intake or at least the demand of certain food items or groups. In rural areas, PN grants additional opportunities for improving the nutritional situation, when food choices are linked to decisions relating the individual agricultural production system causing changes in food production towards nutrient-sensitive agriculture (Figure 4, lower part), which aims, among other, at diversification and sustainable as well as nutritious food production [65].

Using PN via smartphones in rural areas of developing countries is currently limited by availability of suitable devices as well as mobile internet access. However, statistics show an increase in households internet access at home in developing countries from 9% in 2005 to 43% in 2017, which assumes higher coverage of internet every year [66]. In the meantime, PN approaches can be put into practice via suitably equipped advisors (e.g. nurses or community workers).

Effectiveness of PN

Several studies compared personalized dietary advice to untargeted generic advice. Besides proof of principle studies with healthy participants, other studies examined PN in the context of NCDs. To address the question, whether online-based PN is advantageous over generic advice to induce a life style change, the European Food4Me Study was designed as online-based randomized control trial in seven European counties with about 1200 participants. The aim was to compare the conventional one-size-fits-all to a PN approach, involving phenotypic and genotypic data [67]. In the study, feedback was provided as semi-quantitative recommendations, advising the participants to increase or decrease the intake of certain nutrients and food items. The Food4Me Study confirmed that PN based on participants' dietary data is more effective than a general conventional advice. However, advice on phenotypic or phenotypic plus genotypic information did not lead to an enhanced effectiveness of PN [24].

Zeevi et al. incorporated phenotypic parameters including gut microbiota in a machine learning algorithm to predict individual postprandial glucose response. In their sub sequential randomized controlled intervention study, participants with PN based on this algorithm had a significantly lower postprandial response [68]. A study by Wright et al. demonstrated that PN was more effective in increasing the fruit intake in participant with cardiovascular risk factors compared to generalized nutritional advice [69]. Shiao et al. identified significant genetic and nutritional predictors for colorectal cancer. They developed a mathematical model, which can be used for personalized advice in colorectal cancer prevention [70].

PN interventions are mainly conducted and analyzed in developed countries to target obesity and over-nutrition in individuals. In contrast, tailored nutritional advice in developing countries was mainly discussed for certain cohort and sub topics, for example infectious diseases or micronutrient deficiencies. HIV-positive children in Tanzania, for example, have a high rate of under-nutrition, which was mainly due to a low frequency of meals and a poor dietary diversity. It was suggested that PN is helpful to educate households to efficiently use available foods and take care of the special nutritional needs of HIV-positive children [71]. A PN program which adapted to local conditions and particular requirements in South Africa successfully improved the weight status of children less than 5 years, but did not catch-up growth in stunted children within two years [72]. A long-term study within the Middle East and North Africa revealed a nutritional shift towards a "Westernized diet" and it was recommended to tailor nutritional education in order to support healthy diets to decrease the rising burden of chronic diseases [73]. Until now however, and to the best of our knowledge, the concept of PN as a holistic approach to improve behavior change generally towards a balanced diet was theoretically approved, but has not yet been tested in developing countries.

Limitations

Implementing PN in the setting of scarcity is limited with regards to individual, social and technological aspects. Individual aspects include the ability to read and write, as an autonomous usage of PN e.g. as a smartphone application might need written input, e.g. for dietary assessment. However, only about 33% of Benin's population aged 15 years and older is literate, twice as many men than women

[74]. Even if the users could read and write, more than 50 different local languages are spoken in the country, while the statutory national language French is only spoken by about 35% in Benin [75]. Audio systems, pictures or else would enable also illiterate and non-French speakers to take part. The social and religious dietary habits are as diverse as the different languages, thus PN in Benin should include the different food taboos to ensure compliance and reduce the risk for diseases, which are connected to the restrictions [76,77].

Conclusions

In the last years, PN gained momentum, in science but also in public. The science on PN provides use-oriented research, involving members from a variety of disciplines, such as life and behavioral scientists, psychologists, informatics and data analysts as well as sensor technology experts, and agro-economic specialists.

For future applications of PN, the development of valid, affordable, and easy-to-use data collection methods, especially for an objective measurement of food intake as well as blood analyses, can help to better display the individual behavior and metabolism to find relevant parameters for behavior change. Genetic research may reveal new interaction of genes and nutrition and produce possible ways to affect the health outcome. However, dietary behavior is driven by various aspects; thus, further studies should implement advice also involving the respective environmental, social and demographic context. The inclusion of factors as market prize analyses, soil potential and mechanization can contribute to a personalized recommendation on agricultural level, for example in rural Africa. Additionally, the inclusion of personality and education, i.e. grade of self-confidence or stamina, and of the ability to read and understand explanations will pave the way to better analyses of the current status, and improved modes of communication of personalized advice to the recipient. A larger involvement of general health care may be implemented, including guidance to take medical check-ups or indicate nearest health centers for specific tests.

While mainly discussed in the context of Nutrigenetics and obesity, a broader view on the PN concept reveals enormous possibilities in various environments to educate the public and contribute to a nutritional-balanced environment worldwide. It provides the opportunity to individually take responsibility for the own health in a most comprehensive way.

Author Contributions

Conceptualization, S.K, K.G.; writing-original draft preparation, S.K.; writing-review and editing, K.G.; supervision, K.G.

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Conflicts of Interest

The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

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