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APPLICATION OF BIOINFORMATICS IN FOOD QUALITY CONTROL

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Abstract:

Bioinformatics will provide details of the molecular basis of human health. The immediate benefits of this information will be to extend our understanding of the role of food in the health and well-being of consumers. In the future, bioinformatics will impact foods at a more profound level, defining the physical, structural and biological properties of food commodities leading to new crops, processes and foods with greater quality in all aspects. Bioinformatics will improve the toxicological assessment of foods making them even safer. Eventually, bioinformatics will extend the already existing trend of personalized choice in the food marketplace to enable consumers to match their food product choices with their own personal health. To build this new knowledge and to take full advantage of these tools there is a need for a paradigm shift in assessing, collecting and sharing databases, in developing new integrative models of biological structure and function, in standardized experimental methods, in data integration and storage, and in analytical and visualization tools.

Introduction:

Bioinformatics and genomics are rapidly expanding fields of technology in Life Science Research. Bioinformatics and knowledge integration have played and will continue to play a enabling role in Food Research integrating the massive amounts of data that are generated through new genome-wide experimental procedures with other more traditional techniques. Bioinformatics is defined as: ''Research, development, or application of computational tools and approaches for expanding the use ofbiological, medical, behavioral, health and nutrition data, including those to acquire, store, organize, archive, analyze, visualize or build bio-logical knowledge from very large and traditionally unrelated sources''. It is about to revolutionize biological research and more importantly to apply this research to the human condition. Bioinformatics has, out of necessity, become a key aspect in Life Science Research and Food Research. Bioinformatics is essentially a cross-disciplinary activity which includes aspects of computer science, software-engineering and molecular and physiological biology. The database management seems to be the major task, bioinformatics goes much deeper; it provides possible gene-function and cellular role of molecular entities, new theoretical frameworks for complex biological systems and new biological hypotheses for wet-lab research. The combination of genomic data, information technology and other advanced research tools will give biologists the opportunity to think more broadly-to investigate not only the workings of a single gene, but to study all of the elements of a complex biological system at the same time.

The same knowledge doctrine is applicable to food science. Food science is a coherent and systematic body of knowledge and understanding of the nature and composition of food biomaterials, and their behavior under the various conditions to which they may be subject. Food technology is the application of food science to the practical treatment of food materials so as to convert them into food products of the kind, quality and stability, and packaged and distributed, so as to meet the needs of consumers for safe, wholesome, nutritious and attractive foods. (http://www.ifst.org/fst.htm). The food science integrates the knowledge of several sciences. It includes the knowledge of the chemical composition of food materials, their physical, biological and biochemical properties and behaviors as well as human nutritional requirements and the nutritional and trophic factors in food materials; the nature and behavior of enzymes; the microbiology of foods; the interaction of food components with each other, with additives and contaminants, and with packaging materials; the pharmacology and toxicology of food materials; and the effects of various manufacturing operations, processes and storage conditions; Thus, food science is an information-based science which integrates knowledge from widely disparate sources. The food industry is directed by the consumers need for high quality, convenient, tasty, safe and affordable food. The scientific advances in genome research and their biotechnological exploitation alike represent unique opportunities to enhance food performance and to build sound scientific knowledge about its multiple functionalities. In the era before bioinformatics and genomics, biological effects were measurable only according to markers for specific conditions (e.g. nutrient deficiencies and impairment of health). Research was therefore targeted solely to consumer health problems such as high blood pressure, high cholesterol, lactose intolerance, osteoporosis and diabetes. As our biological knowledge develops in this new era, metabolic conditions consistent with improvements in health will be the new markers. This knowledge will allow intervention through foods to prevent health problems long before deleterious effects are apparent and the consumer will finally take advantage of the technological breakthrough in these areas which will yield healthy, high quality foods with positive nutritive properties. This is just a part of the promise of how new scientific knowledge of food, gained and made available through bioinformatics will influence the everyday lives of consumers.

The Impact of Genomics on the Quality Assurance of Foods:

Food safety is becoming more and more a major area of concern for consumers and the food industry has developed a coherent research programme to ensure food safety with well-established classical methodologies but also new state-of-the-art research tools. The goal here is to ensure that the inactivation or inhibition of undesired microbes is possible using the minimum treatment of foods necessary, to increase the under-standing on the ecology of food-born microbial populations, to find-out how thesepopulations respond to environmental factors like stress and last but not least the toxicological evaluation of foods and food compounds. The genomics era delivers many new tools like proteomics and DNA-array technology to tackle the above mentioned problems. These new technologies are now a vital part of the scientific strategic plan to serve the diet and health theme and to provide safe food to the consumer.

Flavor Analysis:

The complex flavor profiles of many delightful commodities (e.g. fruits, baked goods) are not due to single compounds but rather are the result of the presence and interactions of literally dozens of different molecules. This knowledge will provide the link and the compiler integrating processing, quality and nutrition paving the road for new product development based on insight knowledge of actual consumers' preferences and needs.

Metabolic Pathway Reconstruction:

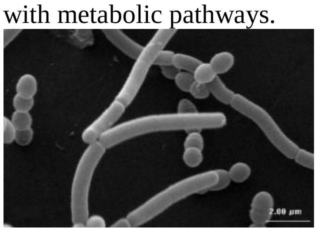
Microbial metabolism has been the basis of a major segment of food processing for centuries. Fermentation of food takes advantage of the ability of desirable microbes to convert substrates (usually carbohydrates) to organic tailor-made compounds contributing to the flavor, structure, texture, stability and safety of the food product. Due to its fundamental importance to such a wide variety of foods from breads to cheeses, wines to sausage, literally over a century of research has focused on understanding microbial metabolism. The potential to build this knowledge into even greater value in foods has been dramatically expanded by the availability of tools to understand and control microbial metabolism using modern genomic and bioinformatic approaches. The production of diacetyl, alanine and ethanol from this sugar metabolism has already been engineered in lactic acid bacteria. With the metabolic reaction network established it becomes possible to determine its underlying pathway structure by pathway models (Schilling & Palsson, 2000). An important approach to a holistic look at such biological processes uses genomic information to reconstruct entire metabolic pathways. The matching of well annotated genes and their expression level from a new organism with a collection of known metabolic pathways from databases is already feasible today.

Implication of Genomics/Bioinformatics for Health and Nutrition:

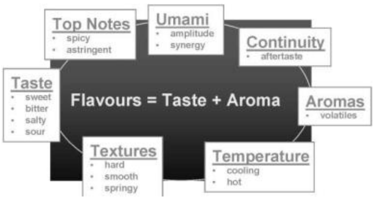
Genomics, enabled by bioinformatics will contribute to an improved understanding of the molecular mechanisms underlying the relationships between food and health, from basic nutrient actions to the interactions between food microorganisms and the human intestinal system, including the gut and immunocompetent cells, and the mechanisms underlying the interactions of the microbial community in the intestinal tract (German, Schiffrin, Reniero, Mollet, Pfeifer, &Neeser, 1999). With the recent explosion of genome data, including genomics, transcriptomics, proteomics, metabolomics and structural genomics, bioinformatics is addressing the task of developing computational methods to deal with the massive flows of data emerging from modern experimental approaches in relating genotype to phenotype (Lee & Lee, 2000). The approaches include functional and comparative genomics and high-throughput technologies such as genome sequencing and DNA microarrays. The knowledge developed from this new science will expand nutrition in three dimensions, mechanism, human variation and time: the genetic mechanisms underlying health, the basis of individual variations in metabolism and the time scales during which diet influences metabolism. The scientific knowledge of both the genetic variation amongst humans and the response of individual genes to ingested molecules (drugs, foods and toxins) is growing exponentially as a result of the arrival of the human genome and the tools of functional genomics (DNA arrays, etc.). This explosion of information is only being converted into usable knowledge because of the arrival of the massive computing power and the bioinformatic tools needed to apply them to large data sets being generated by nutrition-related research. This knowledge will not only drive a new generation of foods with additional values but change dramatically the ability of foods to influence individual quality of life. This knowledge promises also to drive a new value system for agriculture itself.

Genetic Responsiveness or Gene Expression:

The ability of nutrients to directly control the expression of particular genes is at the heart of a new generationof nutritional science allowing researchers to apply genomic information to technologies that can quantify the amount of actively transcribing genes in any cell at any time (e.g. gene expression arrays). With this technology in place, scientists of every biological discipline are discovering the interaction between organisms and their environment with an intimacy never thought possible. Nutrition is at its heart, a multidisciplinary field focusing on integrative metabolism of animals and humans. Nutritionists have strived for the last century to deduce the mechanistic basis of the apparent strong relationship between diet and health through under-standing the interaction of nutrients with metabolic pathways.



Electron micrograph of Streptococcus thermophilus (oval chains) and Lactobacillus johnsonii (rod-like chains) cells used for starters cultures in food fermentations.



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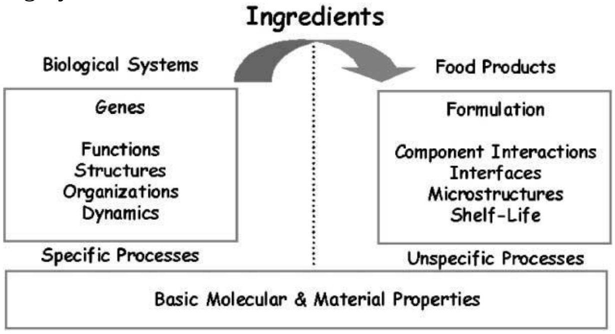
The perceived food qualities are driven by flavors and texture. Both are composite events whose disparate elements show specific interactions. While the elements can be controlled separately, only understanding the underlying neurophysiological processes will lead to optimizing the flavor and texture impact of foods.

Example of a Cacao plant (Theobroma cacao L.) in natural form as fruits, as beans and finally as ground powder. Cacao trees must be maintained approx. 3–5 years before harvesting the cacao. Selection of specific traits based on genotype in the early development of the plant is therefore highly desirable.



Food production is based on biological raw materials which are refined into food ingredients. A unifiying approach is proposed on the basis of common basic and material properties of the comprising molecules in both domains. Moreover, the vast store of knowledge currently being produced by the biomical sciences (genomics, proteomics, metabolomics) will improve the knowledge on ingredient characteristics and behaviours.

Bioinformatics and Food Processing:

The most immediate application of bioinformatics to food processing will be in optimizing the quantitative compositional parameters of traditional unit operations. Food commodities are processed largely to achieve storage stability and safety with considerable excess of energy applied to ensure a large margin for error. This margin of error is necessary due to our inexact knowledge of the composition and structural complexity of biological materials, the natural variability of living organisms as food process input streams and the response of these materials to processing parameters. With the considerable knowledge of biological organisms from bacteria and viruses to plants and animals that is emerging from bioinformatics, food process design will become optimized with narrower margins of all cost-important inputs, especially energy. The great future for food processing however is not in simply processing for greater safety, but in merging biological knowledge of living organisms with the bio-material knowledge necessary to convert them to foods. Traditional food processing relies on the aggressive input of energy to restructure the biomaterials of living organisms into simpler macrostructure forms of stable, relatively uniform foods. In most cases the inherent biological properties of the living systems are lost to the final food product in the need to eliminate potentially hazardous properties of some of the constituent molecules (protease inhibitors, etc.). The arrival of the knowledge base of modern bioinformatics, however, is providing a detailed description of the inherent complexity of biological macromolecules within living cells together with the structural properties of these molecules that provide much of their functions. Such knowledge is the cornerstone of functional genomics and proteomics. The arrival of such knowledge, however, provides an unprecedented opportunity to translate this knowledge into an equally accurate assessment of the biomaterial properties of each of the molecules in a complex mixture. It will soon be possible to use the inherent structural properties of natural food commodities to self-assemble new foods with a minimum of external energy retaining a maximum of biological and nutritional value.

All foodstuffs are ostensibly modified tissues. Thus, the natural biomaterial properties of the molecules that make up living organisms underlie the basic biomaterial properties of foods. In most traditional food processing, however, little advantage is taken of the unique properties of specific molecules and instead, all bio-molecules of a particular class, e.g. proteins, are exposed to substantial physical, thermal and mechanical energy to make these properties uniform in order to restructure the material into more stable, and/or more bioavailable food systems. Such processing eliminates the subtle differences within most of the classes of the major bio-molecules that are inherent to and the basis of complex structure–function relationships of living organisms. Processing replaces biological complexity with the statistical average properties of the broad classes of biomaterials, i.e. proteins, carbohydrates, lipids. The processing of commodities to eliminate the complexity of their biological structures are not necessary to the quality of foods, in fact the opposite. There are vivid examples in which highly specific biological properties of the original living organism are a key to the processing strategy and ultimately the organoleptic attractiveness of final food products. The renneting of bovine milk to induce the natural aggregation of milk caseins leading to the gelation events of cheese manufacture is such a process. The final product takes advantage of the unique self-assembly properties of milk casein micelles

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that are colloidally stabilized in milk by kappa caseins but destabilized when enzymatically cleaved of their solubilizing glycomacropeptide. Another example is leavened bread in which a combination of both composite processing and biological restructuring is the basis of breads' structures, textures and nutrition. In this case, wheat seeds are ground to disassemble the majority of their biological structures through mechanical energy, but then the biological processes of yeast fermentation achieve simultaneously the enzymatic elimination of phytic acid during dough incubation and the biochemical production of carbon dioxide gas as leavening within a mechanically reworked protein gel structure. In each of these cases, bread and cheese, taking advantage of the biological properties of the living organisms, led to substantial value both organoleptically and in greater safety and nutritional value. Furthermore, the inherent variation in biological organisms that plagues the standardization of simpler food processing objectives is not a disadvantage to these two food staples, but rather a wonderful benefit leading to literally hundreds of distinctly flavored and textured cheeses and varieties of breads. Thus, cheeses and breads provide proof of what is possible when the bio-logical processes of catalysis, self-assembly and restructuration is retained as the basis of food processing. Heretofore, empirical trial and error was the major route to discovery of biodriven food processing. However, the biological knowledge that is emerging with functional genomics, proteomics and metabolomics is providing precisely the knowledge necessary to read-dress food processing using bimolecular activities rather than simply composite biomaterial properties.

Conclusion:

Biomics, comprised of genomics, proteomics and metabolomics, is taking up its position as a lead science for the 21st century. Its influence is already felt throughout the biological sciences. Moreover, its influence on nutrition and food science will generate a unified area of research where both nutritional benefit and traditional food values become parts of an extended life science driving towards enhanced quality of life. Impacts of the knowledge obtained through this research on raw materials, ingredients, safety, quality and nutrition can be expected to have a far greater impact on product improvements than today's functional food research is imagining. Future developments in biomics, bioinformatics and information technology based approaches to foods will truly change and revolutionize the way food industry will satisfy consumer needs and wants.

Recommendations:

1. Raising awareness among people about the role of bioinformatics in food quality control.
2. Toxicological assessment of foods using bioinformatics is the thrust area of research.
3. Near future, bioinformatics will extend the personalized choice in the food for their own personal health.

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