Technological Progress as a Driver of Innovation in Infant Foods

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Abstract

Advances in nutrition and food sciences are interrelated components of the innovative framework for infant formula and foods. While nutrition science continues to define the composition and functionality of human milk as a reference, food ingredient, formulation and processing technologies facilitate the design and delivery of nutritional and functional concepts to infant products. Expanding knowledge of both nutritive and non-nutritive components of human milk and their functionality guides selection and development of novel ingredient, formulation and processing methods to generate enhanced infant products targeting benefits including healthy growth, development as well as protection of health through the life cycle. In this chapter, identification and application of select novel ingredients/technologies will be discussed in the context of how these technological advancements have stimulated innovation in infant foods. Special focus will be given to advancements in protein technologies, as well as bioactive long-chain polyunsaturated fatty acids, prebiotics, probiotics that have allowed infant formula composition, and more critically functionality, to more closely align with that of human milk.

Introduction

Innovation is critical to continually improve the quality and accessibility of infant foods worldwide. As these products are designed to support the health and development of the infants who consume them as a primary or sole source of nutrition, innovation in infant foods must be a continuous process involving improvement in product nutritional quality, functionality and/or the delivery of a quality product to consumers for enhanced value. Apart from non-technical factors such as market and economic forces, food
Science and nutritional technologies are often considered primary drivers of innovation in the food industry. Both groundbreaking as well as incremental technological innovations are critical in the infant food industry. These innovations arise primarily from (1) scientific advancement in infant/child nutrition, (2) development of novel ingredient technologies, (3) advancements in food safety technology (processing, packaging, etc.), and (4) the science of consumer insight and behavior as it relates to infant feeding. While each area is critical to continuous innovation of infant foods, parallel advancements in nutritional and food sciences play a central role in driving infant food innovation. This is largely due to continuous research on both nutritional and functional properties of human milk, and subsequent translation of this knowledge into formula through creation and application of novel food ingredients, compositions and food processes [1]. This chapter specifically focuses on how the fundamental understanding of the composition of human milk has expanded to include both nutritive and non-nutritive components with important biological activity, and on how these findings have driven recent innovations in infant formula. The application of select ingredients and technologies will be discussed in the context of how these advancements have enabled the industry to more closely align infant formula functionality with that of human milk.

Exploring Human Milk Composition and Functionality as a Source of Innovation

The characterization of human milk composition and function, in relation to infant nutrition, has resulted in the definition of an adaptable and evolving ‘gold standard’ for infant formulae [2]. Human milk contains components, both nutritive and non-nutritive, that support healthy growth, development, proper immune function, and provide many other functional benefits to the infant [3]. As the body of knowledge regarding human milk composition and functionality matures, manufacturers strive to innovate by applying novel nutritional or functional ingredients or concepts to adapt infant formula profiles in an effort to better emulate the benefits of human milk and breastfeeding [1] (fig. 1). This approach requires the translation of nutrition science through food and ingredient technology to generate innovative impactful products of high quality, stability, safety and value for consumers (fig. 2). This is particularly true in cases where functional components of human milk may not be commercially available in a fashion matching the naturally occurring components. For example, improved understanding of human milk protein composition has led to adjustments in total protein content and the ratio of bovine whey to casein in infant formula to better mimic human milk composition and nutritional value [4]. Characterization of long-chain polyunsaturated fatty acids (LC-PUFAs) in human milk and their association with infant eye
Nutritional and physiological considerations
- Nutrient and bioactive composition
- Bioavailability
- Growth and development
- Tolerance
- Physiological functionality

Fig. 1. Technological advancement drives innovation in infant foods. Technological advancements in nutrition science provide critical information on composition and functionality of human milk. Advances in food science, ingredient technology and consumer insight allow for translation of nutrition science into infant formula and foods.
and brain development has led to development of algal- and fungal-derived lipids suitable for enrichment of these fatty acids in infant foods [5]. More recently, the carotenoid pigment lutein has been added to select infant formulae in the US as a biological antioxidant, supported primarily by the carotenoid content of human milk and proposed but not fully demonstrated roles in eye development [6]. Examples illustrating how characterization of nutritive and non-nutritive components of human milk and their function has driven innovative adaptation of infant formula are discussed below.

**Nutritive Components of Human Milk as a Source of Innovation in Infant Foods**

The macro- and micronutrient profile of human milk is highly variable, and depends on several factors including the nutritional status of the mother and the extent and duration of nursing. Human milk composition also changes along with the needs of the growing infant. Despite this variability, the key

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**Fig. 2.** Translation of innovations in nutrition science research into infant products is incrementally achieved through technological advancements in food technology. Design and development of infant products with novel ingredient technology is followed by rigorous assessment of quality, safety and ultimate efficacy through well-designed clinical trials prior to industrialization and commercialization. Consideration of ingredient/technology scalability, cost in use and regulatory compliance is critical to successful development. Additional consideration of consumer needs and expectations may enhance the acceptability of nutritionally and technologically innovative products.
nutritive components of human milk appear to be carbohydrates, lipids, proteins, vitamins, minerals, and several other growth factors [3]. Additionally, knowledge of the differences between human and bovine or goat milks (from which infant formula is typically made), have provided opportunities for innovation in the design of macro- and micronutrient profiles in infant formula in order to better mimic human milk. The following examples illustrate how knowledge of the composition and functionality of select nutritive components of human milk has driven innovation in infant formula.

**Protein Sources, Composition and Fractions**

The source, composition and nutritional value of protein utilized in infant formula should mimic human milk protein with regards to nutritional quality and tolerance. This is particularly challenging with standard protein-based ingredients, considering the highly variable nature of the protein and amino acid content of human milk [3]. Infant formula is largely produced using bovine milk or soy protein isolates, with defined minimum and maximum values for optimal infant growth and development [4]. This reliance on bovine and soy ingredients has required innovation in protein technology, to generate protein ingredients and/or compositions that better mimic human milk quality and tolerance. Specifically, technological advancements in base protein ingredients include the generation of enriched whey protein fractions, expanded availability of partially and highly hydrolyzed bovine milk proteins, and development/application of specific soy protein isolates. These improved proteins have facilitated development of products with improved digestibility and lessened potential for allergenicity from bovine or soy products [7]. These technological advances have resulted in innovative products that more closely resemble the nutritional quality and function of human milk and provide consumers additional flexibility in selection of infant formulae.

Beyond protein composition, identification of specific functional proteins and bioactive peptides in human milk has provided an additional source of product innovation. For example, lactoferrin is a significant component of the whey fraction of human milk. Several associations have been identified between lactoferrin and infant growth and development, including improvement of iron absorption and immune enhancement through modulation of GI flora [8, 9]. While present in human and bovine milk, the concentration of lactoferrin is 5-fold to 10-fold higher in human milk. The high concentration in human milk, combined with the potential activity of lactoferrin (particularly as an immune-enhancing agent), has stimulated interest in the role of lactoferrin in infant growth and development and, by extension, has led to interest in the enhancement of lactoferrin levels of infant formula to more closely approximate levels in human milk.

Significant efforts have focused on development and assessment of bovine lactoferrin isolates for targeted enrichment of infant formula. Specific
challenges associated with the development of lactoferrin ingredients include stabilization of protein functionality through thermal processing common to infant formula, as well as assessment of its impact on product quality markers (oxidative stability, etc.) [8, 10]. Following the successful development and safety assessment of bovine lactoferrin ingredients, GRAS status was achieved in 2003. Lactoferrin is now commercially available and is used in infant formulae globally. More recently, the characterization of bioactive peptides derived from hydrolytic lactoferrin digestion (lactoferricin) has drawn additional attention due to the potential antimicrobial and immune stimulatory activities of this hydrolysate [8] as well as its potential for enhanced product functionality and stability. Future innovation in protein ingredient technology for infant formula will likely involve characterization of specific bioactive peptides present in the infant gut and development of strategies to optimize delivery and stability of these bioactive peptides to the infant.

**Long-Chain Polyunsaturated Fatty Acids**

Another example of how advancements in infant nutrition have directly translated to innovations in infant foods involves LC-PUFAs. LC-PUFAs (including docosahexaenoic acid, DHA, and arachidonic acid, ARA) are relatively minor components of human milk, representing ~0.1–4% of the total fatty acid content of milk from healthy mothers. Levels of LC-PUFAs in human milk vary by geographical region and dietary patterns; higher levels are often associated with higher intakes of fatty fish [11]. While LC-PUFAs are minor components of human milk, evidence of functional roles for DHA and ARA in brain and eye development have been identified through significant research efforts, resulting in recommendations for DHA and ARA addition to infant formula at levels between 0.2 and 0.5% of the total fat [12].

A critical technological hurdle for inclusion of DHA and ARA into infant foods was the need to identify a sustainable, high-quality source of these bioactive lipids. While fatty fish represent the primary dietary source of LC-PUFAs, several challenges exist with marine sources of these lipids, including sustainability and variability in fatty acid composition including higher levels of eicosapentaenoic acid. Development of sustainable algal (*Crypthecodinium cohnii*) and fungal (*Mortierella alpina*) sources of DHA and ARA which provide high-quality, consistent lipid composition has facilitated the progression of DHA and ARA functionality beyond the science and into practical product application [13]. The application of DHA and ARA in infant foods remains an example of how functionality, rather than a rationale based purely upon composition, was effectively utilized as a driver of innovation. Expansion of DHA and ARA into products such as follow-up formula, children’s products and mother’s supplements further highlights the importance and success of these ingredients.
Non-Nutritive Components of Human Milk as a Source of Innovation in Infant Foods

In addition to nutritive components, characterization of non-nutritive constituents in human milk, such as prebiotic oligosaccharides, probiotic microorganisms and phytochemicals, are a source of innovation for infant foods. Advancement of our understanding of the functional roles these components may play in support of infant health and well-being has stimulated interest in the development of relevant ingredients and strategies for their application in infant foods. A few key examples of how non-nutritive human milk components have driven recent innovation in infant formula are described below.

Milk Oligosaccharides

More than 130 human milk oligosaccharides (HMOs) have been characterized. The majority of known HMOs are primarily composed of five monosaccharides: D-glucose, D-galactose, N-acetylglucosamine, L-fucose, and sialic acid [14]. HMOs are significant components of human milk (present at ~5–10 g/l). HMOs are believed to possess a broad array of functional properties including prevention of intestinal infections, inhibition of pathogenic bacterial adhesion, prebiotic functions, prevention of allergies, and immune enhancement [15]. Commercial sources of natural oligosaccharides similar to those in human milk do not currently exist. The general absence of a natural or synthetic compositional mimic to the complexity of HMO remains a significant technological hurdle to fully leveraging this scientific knowledge. However, innovation in this area has proceeded through advances in ingredient technology centered on natural and synthetic prebiotic oligosaccharides which mimic HMO functionality but differ in composition from natural HMOs [16].

Use of enzymatically generated and/or naturally occurring plant sources of fructo-oligosaccharides, lactose-derived galacto-oligosaccharides and combinations of these fibers have provided a source of innovation in infant formula [15]. While these non-HMO prebiotic fibers appear to be somewhat less effective than human milk rich in natural HMOs, some potential benefits do exist with regard to prevention of atopic disease. Ongoing research is beginning to address how formulae containing these non-human prebiotic oligosaccharides mimic human milk functionality by promoting growth of infant intestinal flora and infant growth [16]. While promising, application of these non-human ingredients is a good example of an ‘innovative bridge’ to a potentially larger breakthrough. Ultimately, more detailed functional characterization of specific bioactive HMO constituents or mixtures would provide the framework for the synthesis or isolation of bioactive oligosaccharides from other species suitable for inclusion into infant formula and foods [14].
**Probiotics**

Probiotics are live bacteria that, when consumed, illicit a beneficial effect on the host by improving intestinal microbial balance [17]. Benefits associated with consumption of probiotics include improvement in lactose malabsorption and tolerance, enhanced gastric motility, reduced constipation, prevention/treatment of diarrhea, improved immunity and amelioration of atopic diseases and food allergies [18]. Infant formulae with probiotic bacterial strains have existed for over a decade. Several bacterial strains have been identified for addition to infant formula including several *Lactobacillus* and *Bifidobacterium* species [19]. Basic research efforts have also characterized bacterial species endogenous in human milk including *Lactobacillus*, *Lactococcus*, *Enterococcus* and *Staphylococcus* species. These endogenous bacteria are believed to contribute to development of the infant gut microflora [20], and by extension are believed to impart functional benefits to the growing infant, including enhanced immunity. This research has strengthened the notion that addition of beneficial probiotic strains to infant formula is consistent with the goal of mimicking both the form and functionality of human milk. Specific research efforts have further stimulated interest in development and commercialization of unique endogenous probiotic strains isolated specifically from human milk [21]. This evolution from existing exogenous probiotic strains to human milk-specific strains will require significant safety and efficacy testing, but would more closely align infant foods in composition and potential function to human milk. Additional innovation may arise from symbiotic strategies (pro- and prebiotic combinations) and/or characterization of endogenous microbial ecologies specific to regional populations.

**Carotenoids**

Plant-based phytochemicals such as carotenoids also offer a potential source of innovation for infant foods. While the provitamin A and antioxidant activities of carotenoids are well known, the association of specific oxy-carotenoids (lutein and zeaxanthin) with prevention of oxidative retinopathy in infants and age-related macular degeneration in adults [6, 22], has increased interest in these pigments as critical non-nutritive components of human milk. Carotenoid content of human milk is generally proportional to the carotenoid profile of the mother’s diet [23, 24]. Although highly variable, research has identified both provitamin A (α- and β-carotene, and β-cryptoxanthin) as well as non-provitamin A (lutein, zeaxanthin and lycopene) carotenoid species in human milk. Lutein and zeaxanthin selectively accumulate in the macula pigment of the retina and have been directly associated with prevention of associated ocular disorders [22]. Unless specially included by formulation, carotenoid content of standard infant formulae is generally variable and low compared to human milk [25], providing opportunities for innovation. As a result, several natural and synthetic carotenoid
ingredients have since been added to commercial infant formula in the US. While definitive clinical evidence justifying their inclusion is lacking to date, this emerging science has created additional opportunities for innovation in ingredient technology and product concepts. This includes development of concepts focused on synergies between carotenoids and other bioactive ingredients such as DHA to improve infant antioxidant status and support vision and eye health [26].

**Infant Feeding Practices Influence Behavior and Chronic Disease Risk in Adulthood**

While ingredient technology has served as a rich source of innovation, opportunities will also evolve from our expanding knowledge of how infant nutrition and feeding practices may impact chronic disease risk in adulthood. For example, improved cardiovascular disease markers including BMI, lipoprotein profiles and blood pressure in adulthood have been associated with infants fed human milk compared to formula [27, 28]. While the factors responsible for these apparent benefits are not fully understood, both nutritional and behavioral components may be an additional focus area for innovation. Recent evidence suggests that the type of milk (human, bovine or hydrolysate) may have an impact on subsequent food preferences [29], indicating a technological link to future behavior and potential disease risk. Understanding how infant milk/formula composition may influence perceived taste and subsequent food preferences and/or ingestive behavior in adulthood will be critical to development of improved infant products with flavor profiles and delivery systems that favorably impact eating habits and dietary selection in adulthood. Considering the potential impact these outcomes may exert through the lifecycle, this area will likely be a future driver of innovation in infant foods as research elucidating underlying mechanisms may be applied to development of specific formulation and process strategies for infant foods that can positively influence diet-related disease risk and outcomes in adulthood.

**Future Opportunities for Innovation in Infant Foods**

While food and nutrition sciences continue to evolve and converge on health-related end points, future innovations in infant foods will include a focus on identification of novel, bioactive ingredients, preparations and/or delivery systems through the continued study of human milk composition, functionality and feeding practices. Efforts to better mimic human milk will depend on our understanding of this ‘gold standard’, which constantly evolves along with improved technology and investigative approaches. It is believed
that future innovation in infant foods must consider how to best mimic the differences in human milk composition and functionality that occur as a function of lactation stage, region, and mother's diet [2]. This should include a consideration of the complexity of physical, chemical and biochemical interactions between individual nutritive and non-nutritive components and how these interactions influence bioavailability and functionality of bioactive compounds from human milk. With a detailed understanding of composition, interactions and adaptability of human milk, a conceptual framework for development of strategies leading to personalized infant foods as described by Lönnerdal [30] would be facilitated. While food and nutrition sciences continue to converge in an effort to understand and then mimic the complexity of human milk composition to match the nutritional and functional needs of the infant, it is also critical to consider changing consumer demands and perception of product quality attributes (such as demand for organic infant products) when designing infant foods. Continued technological advancement is required in ingredient technology, processing and packaging strategies to better mimic human milk composition, bioavailability of bioactive components and ultimate functionality of infant formula and foods. In all cases, innovation will continue to require a balance between technological progress and assessment of both efficacy and safety of novel ingredients, platforms and finished product concepts.

References


**Discussion**

*Dr. Gibson:* I want to ask you a little bit about your connection to clinical trials and randomized trials to demonstrate clinical efficacy rather than just identifying compounds and assuming that X plus X equals to Y and therefore this is a good thing to be adding. You’ll be well aware of the systematic review and meta-analysis that was done on antioxidants and published in *JAMA* a couple of years ago. They showed quite dramatically that most of those antioxidants were actually harmful and caused more deaths than they did save in people. So we have never been able to find the roles of vitamin E and a number of other so-called antioxidants. I think that putting them in food is quite dangerous. Could you comment on that?
Dr. Ferruzzi: I think those are excellent points and critical issues to address the food science, nutrition science and of course the clinical side. Establish efficacy in large randomized trials would be the ultimate goal. The challenge may be in establishing enough evidence leading up to a large trial. I don’t think we should be adding ingredients based only on in vitro activity. Secondly, and I think your point on toxicity is important, understanding the importance of dose of many of those bioactive compounds such as phytochemicals is critical. Are they better to be consumed as foods? Are they better to be consumed as dietary supplements? Speaking in regard to the infant foods, I think obviously we have to be much more conservative when we are looking for bioactive compounds to innovate from. We have to understand much more about the individual component and its potential interactions before we begin to include these into products and assess outcomes and of course before communication on that.

Dr. Yang: As we know, in breast milk there are many kinds of growth factors such as EGF or IGF. What is your comment on this kind of growth factors?

Dr. Ferruzzi: This is beyond my area of expertise, but it goes back to looking at the fundamental paradigm, which is understanding the human milk composition and function as initial target for innovation. Growth factors added to any formula should strive to emulate function of those from human milk components. So again, this should consider function, safety assessment, understanding really the intended outcomes and intended improvement to a formula.

Dr. Ludan: I want to ask a question about the bioavailability of trace minerals. You mentioned that lactoferrin is a cotransporter of iron. Is there a specific cotransporter of zinc, and is this affected by the type of zinc compounds given because we know there are several zinc compounds available, like zinc gluconate, zinc sulfate, etc.

Dr. Ferruzzi: Sure, there are specific factors associated with zinc absorption and assessment of zinc absorption. Dr. Lönnertal is in fact the expert in this area and we could discuss it in more detail afterwards.

Dr. Bier: This is a little bit aside from the actual point of the talk but I find the slide of the lutein formula astonishing. I would be amazed if you try to get through an IRB in the US an experiment on who knows how many children providing lutein without any evidence at all in an uncontrolled human experiment. I can imagine this would get through any university IRB in the US.

Dr. Ferruzzi: I don’t think you would find much disagreement, at least in this room. I think that was a premature addition to formula considering the evidence. It goes back to justifying addition of bioactive compounds. Is it important just because it’s there rather than why is it there and what is its function and establishing that before moving on to innovation in these specific products, I absolutely agree with that.

Dr. Solomons: It seems that innovation in pediatric nutrition could have two additional suffixes for products and benefits of child nutrition and then the decisions we make regarding how we balance those two would change their context.

Dr. Ferruzzi: I think what’s interesting is to understand the market push to innovation rather than just the technological push, and I think it’s important especially in this area to really stay more on the understanding of the technological push towards innovation rather than exclusively proceeding by market-driven ideas. In the food industry, you see a trend to more market-driven innovation; so it’s a lot of window dressing of products. Back to the antioxidant comment: Sometimes people are advertising antioxidant content, enhanced vitamin and mineral content. It typically has nothing to do with nutrition, rather it’s what is going to process well and not make a product taste bad and sale. So it’s always important to understand that market push. From the infant food perspective, it should clearly be less a market push but rather the context of what the market needs from the standpoint of communication on the
product, how do we better translate the science for the consumer to understand that this is a new and improved product, a better product, providing that we have the science to substantiate that. That not only drives innovation but can drive outcomes, and I think it is important to work with marketing rather than for them.

Dr. Haschke: Coming back to bioavailability, there has been a paradigm for the last two decades that highly bioavailable components are better absorbed, are kept in the body and should be used for fortification. So, the industry was looking for these bioavailable components, let’s say iron, which is easily absorbed, and had a lot of problems in terms of solubility, taste perception. In the more recent literature, it turns out that this might not be so important because if the body has a deficiency, the body takes what it needs. In his population outcome studies, Richard Harrell said that the final outcome is what is in the population, no matter whether you give a salt with low bioavailability or high bioavailability. This is very important, for example for micronutrient fortification of food in the whole world, not looking for the high-fly component, looking for a component which is affordable.

Dr. Ferruzzi: I agree, and I think one of the interesting things from the bioavailability perspective relates to understanding what the product is delivering. But also it offers some opportunities in terms of innovation by synergizing concepts back to food. One of the reasons there is, for example, if rather than looking at blood levels or any specific compound you look at the specific metabolic effect as a marker of bioavailability, you may find you need dose X. That dose may be exceedingly high in food product, and it may cause instability in the food product. The final strategy is to reduce the amount in food to deliver the same benefit, not so much to overfortify, but actually to deliver on the promise of the benefit, bioavailability may be more useful to control cost. If you can use significantly less of an ingredient because you have better bioavailability, you may significantly impact the cost. So there are some opportunities, but I fully agree with you, I don’t think that we should just ‘optimize’ it.

Dr. B. Koletzko: Please allow me to come back to the topic that Dr. Haschke raised on the impact on production technology. We heard a very impressive example by Dr. Lönnerdal demonstrating that a change from powder formula to ready to use liquid formula can basically eliminate all bioactive TGF-β. We have seen other examples that liquid formulas have lower protein quality and poorer absorption of micronutrients. Most clinicians probably aren’t quite aware of the powerful effects of the methodology of production on product quality. You showed an insightful scheme of how the innovative process might work while you develop a product idea. Oftentimes, manufacturers would produce a product in a pilot plant in a small amount and then perform a clinical evaluation with that product. If the study outcomes are satisfactory, one might scale up production and do production on an industrial scale. During that process, product qualities might change. For example, I would assume that the detailed conditions on how one produces a protein hydrolysate really matter for the allergenic properties, and if one thinks about a probiotic product obviously it’s very important how those probiotic bacteria are treated and in which environment they are maintained for their biological activity. Thus, one wonders if formula products produced by a large company in, say, three different plants around the world are truly equivalent, if the conditions of production in those three plants are not exactly the same, for example they use different milk to start with, they have different machines and different technology, and perhaps even different other raw materials added. Also, one would assume that production technology will be modified and improved over time, for example new machines come in, new mineral and vitamin mixes are used, other factors will change, and steps may be taken to reduce costs. Thus, do we really know to which extent this might affect the relevant qualities of the product? What is the degree of quality assurance that can be implemented here to make sure we know what is happening?
**Dr. Ferruzzi:** I have several points to those questions. First, it is important to understand that quality parameters need to be very stringent for a product like infant formula, so whether you are producing it in factory A or factory B or factory C you should see very tight quality parameters. I think we have to understand that from a food processor’s perspective the process more often is related to the ‘first objective’, which is always safety. Usually, that means excessively overprocessing to ensure you have a microbiologically safe product. You additionally want to control spoilage, and then you think about other parameters. How those processes synergize with delivering of the eventual functionalities and clinical outcomes has to be defined. So, it could be that if we are measuring at the standpoint of the standard nutrition labeling and everything else we may not see a difference, but that process may have destroyed other functional factors which were important and may have consequences on functionality. The second point relates to the heterogeneity in ingredient supply. It is important to understand, the source and the quality of the ingredients. It’s up to you, the processor, to specify what you want in terms of quality parameters and ingredients in the finished product and then hold it to that. There are obviously regulatory aspects for some of this, but it is extremely important to understand that the processing strategy and especially the current ones are not always designed; actually, they are almost never designed from a standpoint of the nutritional end point per se, again safety first. Also, scale-up is a real issue. Ensuring that the product that comes out of the factory meets the target you established as a new gold standard which is out of your pilot plant or lab bench is extremely difficult but important. Scaling the process is important but so is scale-up of the ingredient, especially if you have a little-volume high-quality very expensive ingredient. For example, if you have to go from making 10 kg of a bioactive protein to making 10 tons, it may not be quite the same. The best is to be intimately involved throughout that process with the manufacturer of the ingredient and product. These are tremendous challenges, it’s not so much just for infant formula, but food in general.

**Dr. Gibson:** One of the challenges for developing countries is actually meeting their nutritional requirements through better foods. I recently attended the International Congress in Nutrition in Bangkok, and there was a general agreement that this was very hard to do through technology alone, that supplementing foods is very expensive, and that there was a better need. To what degree is there a driver from your point of view in terms of finding better plants or better sources of foods to put into the pipeline?

**Dr. Ferruzzi:** I guess there are two ways to approach that. One is to define better plants, better sources and better ingredients. When dealing with processed food, you have to additionally conform to current processing technology, especially in some of the developing world, rather than trying to bring in something extremely high-tech to do. So, trying to understand what is available locally, what can be used, what can be enhanced to the current techniques. You can use new products, new plants and new sources, but it comes down to integration into the current processing and distribution technology. Not only developing countries are concerned; even in the US we have a difficult time rolling out advanced technologies in food processing due to cost. We hear that a lot, it’s something that is definitely not unique, but it has really been about finding ways to readapt current technologies to some new and novel ingredient sources. It’s interesting because it relates back to the biofortification approach for some of the staple foods/grains such as the golden rice. You may have added ten times more β-carotene to a product, but what if consumers do not want the product?

**Dr. Bodenstab:** I want to add two comments to Dr. Koletzko’s questions about clinical trials. If you produce a product for clinical trials on a pilot plant scale, the later product on the industrial scale may look different. In our company, we frequently do
productions for clinical trials in our factories, on the industrial scale. Or product can be produced in one of our so-called Product Technology Centers where our pilot plant actually is on the industrial scale.

**Dr. Ferruzzi:** That is required actually, that it is actually on the finished product that your evaluation is done, not on the pilot product in some markets.

**Dr. Bodenstab:** Absolutely.

**Dr. B. Koletzko:** But is that a standard generally applied in the industry, or are there variable standards in different companies?

**Dr. Bodenstab:** I am talking about Nestlé. I don’t know about other companies, but we do certainly use industrial scale production methods, not only for clinical trials but also for regular consumer trials. The second comment I would like to make concerns technology. Do all factories perform the same way? Nestlé has around 500 factories globally. In the last 10 years, a huge effort has been made to improve safety and regulatory compliance in what we do. Our standards in Nestlé are global; whether it has been produced in China or in Europe or in the US, we have the same quality and safety standards. It’s not exactly the same at any point in time because a new technology may go into one factory first wherever that may be, but then if it works successfully it goes into other factories. This also has an impact on our understanding of raw materials, in terms of geography and also season; we start to use databases that give us information which allows us to better understand the composition of the raw material and later on the finished product. When talking about innovation, the question that’s very often asked is what is important for consumers. There is another question: What is important for our operations and our factories? This question is much less prominent in the discussion; however, I believe it’s a very important question.

**Dr. Singhi:** I think that one of the issues concerning technology is that we are not giving importance to what is variable, what nature is doing as part of adaptability. We are saying this is infant milk, this is the standard formula for every baby, but nature’s variability, how do you think technology can put that in practice. Also, how can we see that we are not adding too much of the different micronutrients that we have lately learned about into the formula? How do we know that we are not making an imbalance in what is existing, can technology answer that?

**Dr. Ferruzzi:** I have been speaking mostly from the food technology side. I think we also have to understand the technological advances, analytical techniques and experimental techniques. We heard yesterday about the advances in scientific techniques that will allow us to learn significantly more about what the gold standard, human milk, is ‘doing’. The more we learn about the composition of human milk, the more we can begin to probe the questions of interactions, and so we can also do that using similar techniques in the formulas and the products you make. Do we see positive or negative interactions when we combine different micronutrients? The question of adaptability is an excellent one. I think you need someone significantly smarter than me that can tell you how to create a product that I can put on the shelf but it adapts and is personalized during use. Technology gets to the point of being able to tell us maybe what one individual needs over another. Do we create three or four different categories of formulas? Do we further fractionate that into people that need slightly different things? So, it’s not quite personalized but it is slightly modified. But the question is how do you change formulas in terms of adaptation not so much over months and periods of lactation but day to day, hour to hour? Those are very good questions, and I think there is a lot of opportunities to think of creative ways to innovate in these areas.