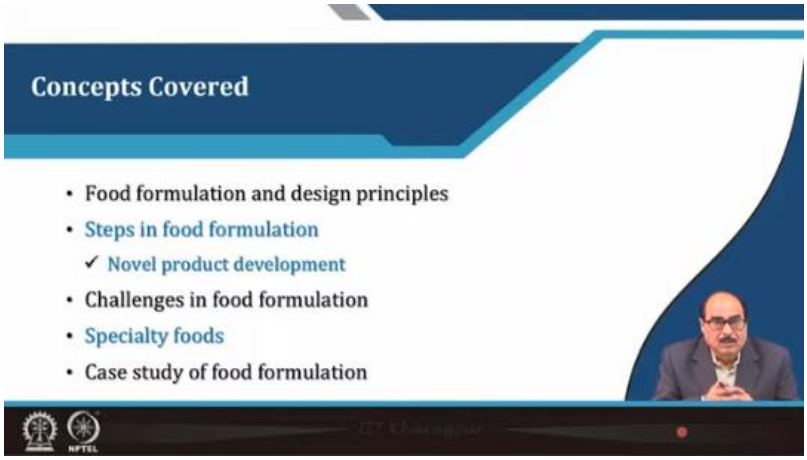
FOOD SCIENCE AND TECHNOLOGY

Lecture 47

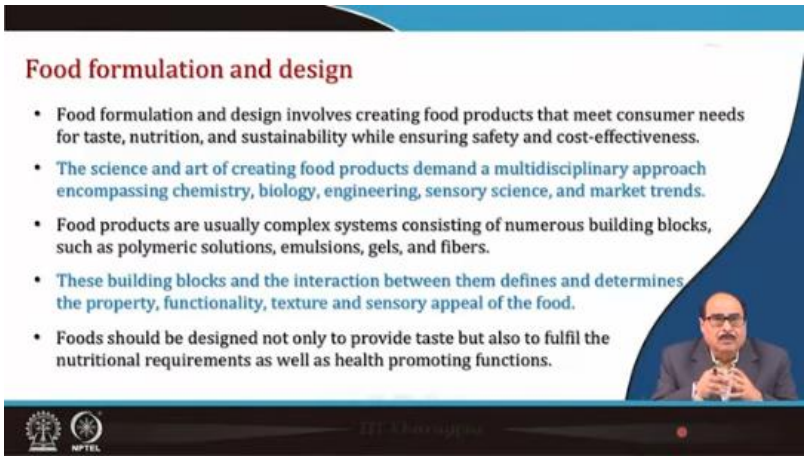
Lecture 47: Food Formulation and Design

Hello friends, Namaskar.

In this lecture, which is lecture 47, in the next half an hour or so, we will talk about food formulation and design.



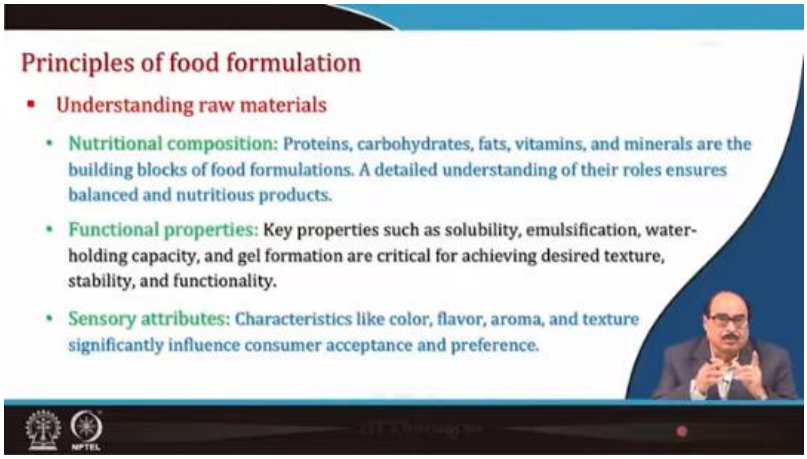
We will discuss the food formulation and design principles, then what the steps are in the formulation of food, particularly new product development, and challenges in food formulation. Then, we will also talk about specialty foods and take one or two case studies for food formulation, okay?



So, food formulation and design involve creating food products that meet consumer needs for taste, nutrition, and sustainability, while ensuring safety and cost-effectiveness. So, the science and art of creating food products demand a multidisciplinary approach, encompassing chemistry, biology, engineering, sensory science, and market trends, etcetera. Because you are dealing with biological materials and materials of different natures, etcetera. And when you formulate or design to get a particular material, we will see in the lectures to come that one must have a thorough understanding of the material type, their interactions, etcetera, and so on. So, food products are usually complex

systems consisting of numerous building blocks, such as polymeric solutions, emulsions, gels, fibers, etcetera.

So, these building blocks and the interactions between them define and determine the property, functionality, texture, and sensory appeal of the final product, okay? Also, food should be designed not only to provide taste, but also to fulfill nutritional requirements as well as health-promoting functions. So, all these things can be carefully done by having a proper formulation strategy or proper designing of the foods.



So, let us see a few details of this: what are the principles of food formulation? So, the first and foremost, a very important thing is understanding raw materials, that is, what is the nutritional composition, like what is the protein content, carbohydrate, fat, vitamins, minerals, etcetera, which are there. Suppose there are 3 or 4 ingredients. So, what are the various nutrients present in that, macromolecules, micromolecules, etcetera?

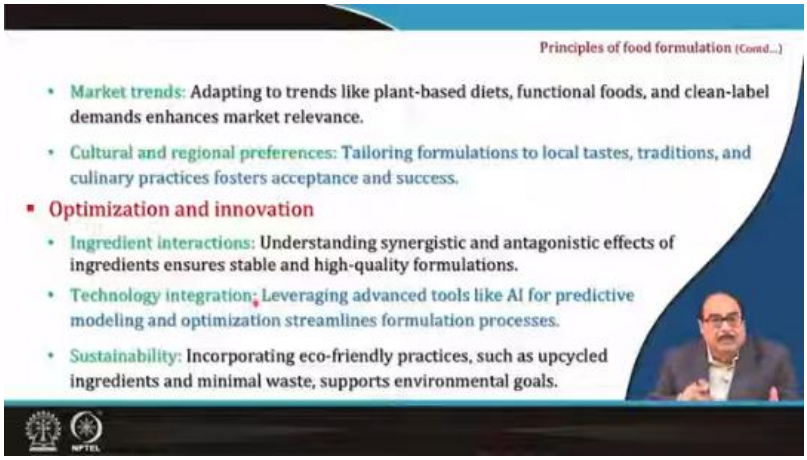
So, a detailed understanding of their roles ensures balanced and nutritious products. Even the functional properties, that is, the key properties like solubility, emulsification, water-holding capacity, gel formation, etcetera. All of these materials one should properly understand because these are critical for achieving desired texture, stability, and functionality in the final product.

Even the sensory attributes, characteristics like color, flavor, aroma, and texture, significantly influence consumer acceptance and preference. So, the materials, their characteristics, their composition, their functional properties, their sensory aspects,

etcetera, all these things should be properly understood, properly studied, and then only you can proceed with the formulation.

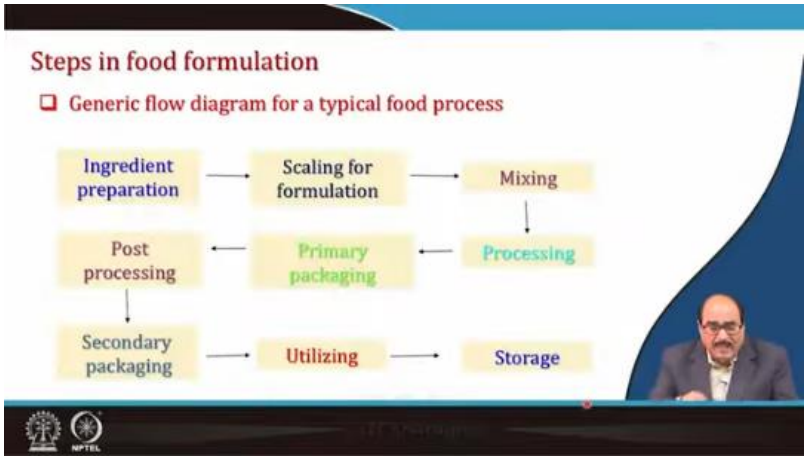
Then another very important thing is regulatory compliance, when you are manufacturing the food, formulating the food, you have to ensure that whatever the ingredients you are selecting their proportions, their composition etcetera. That is whether you are following the food safety standards or not like adherence to regulations like Codex Alimentarius, FSSAI, EFSA and FDA ensure the product safety and legal compliance even labeling requirement must be followed. GRAS like generally recognized as safe that is whatever ingredient particularly additive, preservative etcetera or other which are used. One must ensure that they are all of the GRAS category, all ingredient that are used they are approved for consumption and meet the safety standards.

And then more importantly one should go for the consumer centric design, like a target demographic product must align with the consumer profiles including age, health conditions, dietary performance etcetera like gluten free products, low sugar product, product for sports person, geriatric foods and so on.



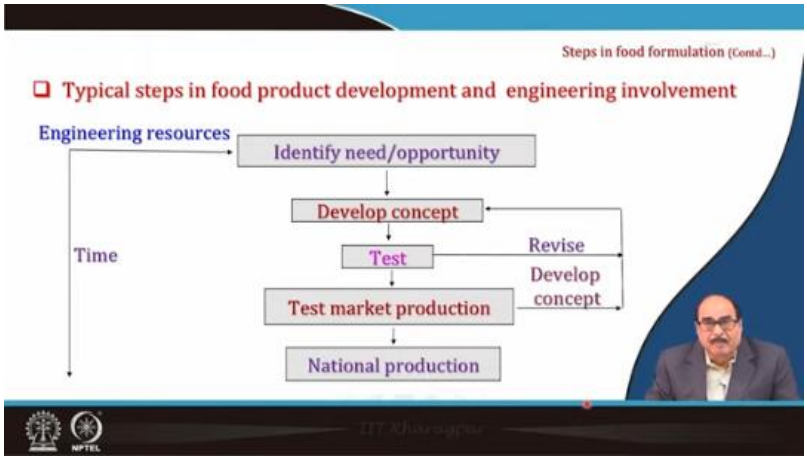
Even the market trends that is adaptation to trends like plant protein diets, functional foods, clean label demands enhance in the market relevance, that is one should see that yes what market needs, what consumer needs and that should become the important criteria for formulating a food, designing a food, manufacturing a food, even the cultural and regional preferences like tailoring formulation to local taste, traditions and culinary practices fosters acceptance and success of your product.

Then optimization and innovation very important from processing point of view, like you have to understand the ingredient interactions, understanding synergistic and antagonistic effect of ingredients, and so as to get a stable and high-quality formulation. Then technology integration like leveraging the advanced tool like artificial intelligence, machine learning etcetera, or automation processes for productive modeling and optimization is streamlines the formulation process. Then sustainability today we more and more effort focus on that is incorporating eco-friendly practices, such as upcycled ingredients and minimal waste support the environmental goals. So, these are the basic principles that one should follow during formulation and design of a food material.

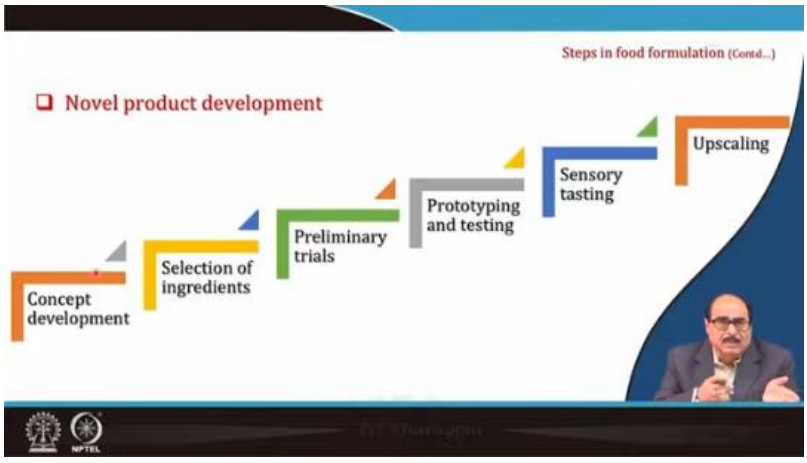


Here I have tried to give you the generic flow diagram of a typical food process whatever food you take, first thing that is you need to prepare the ingredient in the last class we discussed about that is maybe you have to go for peeling, sorting, grading, grinding, reducing size whatever in part, that is you have to prepare the ingredient by using one or the other. Then scaling for the formulation, then scale it down as per the formula whatever as per the proportion etcetera that has been designed properly maybe we will discuss today's class or in the next class in the mathematical tools for formulation and design and then and then we go further.

Mixing operation, because, majority of the food processes, they involve one or the other type of mixing. It may be solid to solid mixing, it may be solid to liquid mixing, liquid to gas mixing, gas to solid mixing, different types of mixing. So, go for mixing, then processing, primary processing, then post processing operations, it should be subjected to secondary packaging. Finally, utilizing or sending it to warehouses, market storage etcetera. So, these are the generic steps in the food formulation and production.



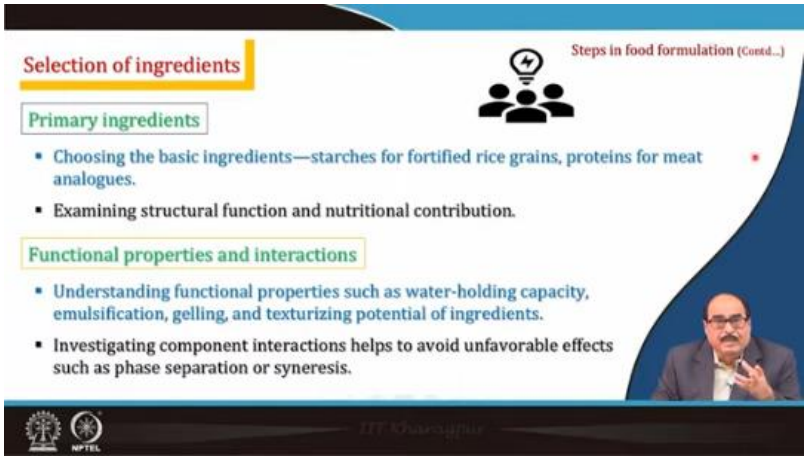
Steps in the food product development and engineering involvement, there is that you have to identify the need or where is the opportunity. and depending upon the engineering resources, financial resources which are there at your disposal. Then you develop your concept, test the concept, if the in the small-scale testing in the laboratory testing if the concept is ok. you go for the market, large scale production or national production. Otherwise sometime if there may be laboratory test is ok and it in the pilot scale testing market production pilot scale testing it may fail then you have to go either revise or develop whole concept altogether a new. So, this is the, but one has to be very careful that is while doing all these things the time elapsed should be as minimum as possible. Otherwise in this competitive age that is era somebody will bring out the product. So, you have to be very careful.



These are the steps we have seen that is in the product development in a new product development like concept development, selection of ingredient, preliminary trials,

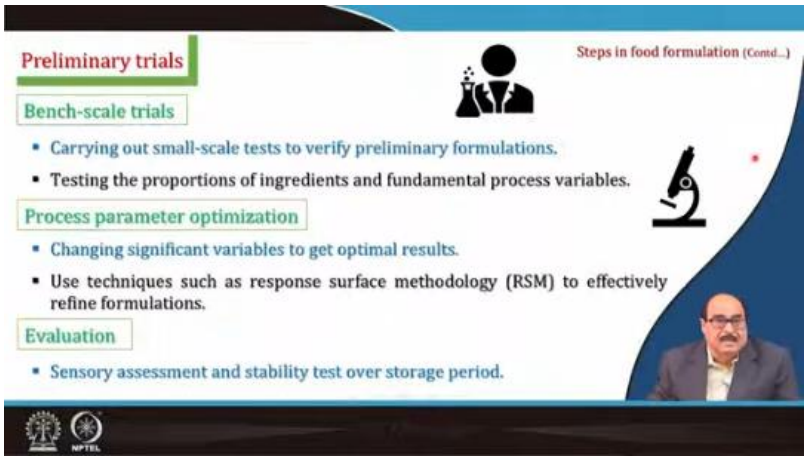
prototyping and testing, sensory testing and finally, upscaling and large-scale production. So, these are the stages how you move in the new product development.

So, in the concept development like ideation say determining the customer requirements based on the demographic analysis, health patterns, personal preferences for living etcetera. Even create product ideas by utilizing focus groups brainstorm, you can conduct brainstorming session or have market research surveys etcetera on the basis of that you have your idea and of course. This idea will be should be feasible that technically it should be sound that is the product and technology match. There should be financial requirement if the product cost effective, cost of the raw materials, products, operation and all those things, and then determining the scalability and production logistics. So, all these things you once you thoroughly study and then you have your idea, a concept.



And then for the once you have finalize your concept develop your concept then go for the selection of the ingredient means what are the primary ingredient like choosing the

basic ingredient like for the fortified foods or fortified staples fortified rice etcetera starches for the even meat analogues, vegetable meats if you want to prepare what are the type of the protein nature of the protein from which you should get good quality protein etcetera. Then examining the structural function and nutritional contribution made by these ingredients. Understanding functional properties such as water holding capacity, emulsification, gelling, texturizing potential of ingredients. Investigating component interactions help to avoid unfavourable effects such as phase separation or syneresis etcetera.

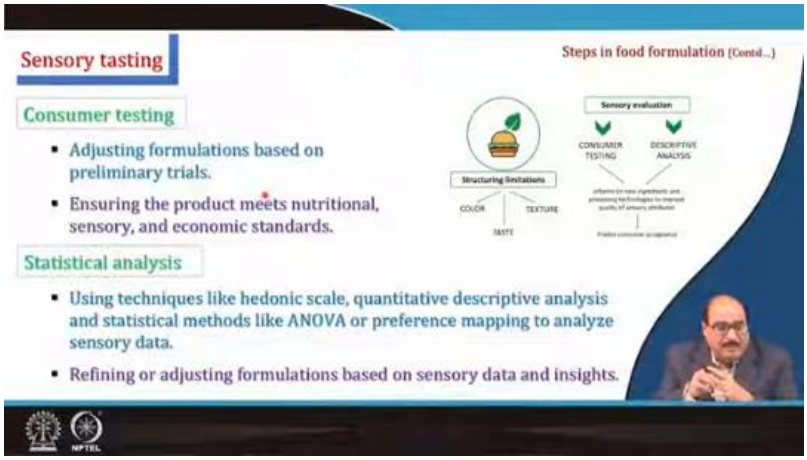


So, all these things that is the ingredient once you have selected considering all these points, then go for the primary trials, like batch scale trials, carry out a small laboratory tests verifying preliminary formulations, testing and proportion of ingredients and fundamental process variables should be done. Then one should go for the process parameter optimization by changing the significant variables to get optimum results and use techniques such as response surface methodology or other mathematical tools to effectively refine your formulation. And finally, that one should have a proper evaluation strategy like sensory evaluation or stability test over storage period or such other test as applicable to the product one should go.

And then one should conduct primary laboratory trials and once this is the primary from the laboratory trials the material is ok, then you go for the prototyping and testing of the prototype. The final optimized product that adjust the formulation based on the preliminary trials and ensure the product meets a nutritional sensory and economic standard and go for the upscaling of the formulation to semi industrial scale, and testing for consistency and identifying potential production challenges.

And, then finally, again here also evaluation of the properties. And, you will find many times that is in the laboratory scale when you are having a small amount of ingredient, where in a few grams and the process which you have optimized when you go for the prototype and then finally, large scale where thousands of kg, 100 kg, 1000 kg of the ingredients are there, they are mixes heated etcetera. So, altogether the process parameters may change.

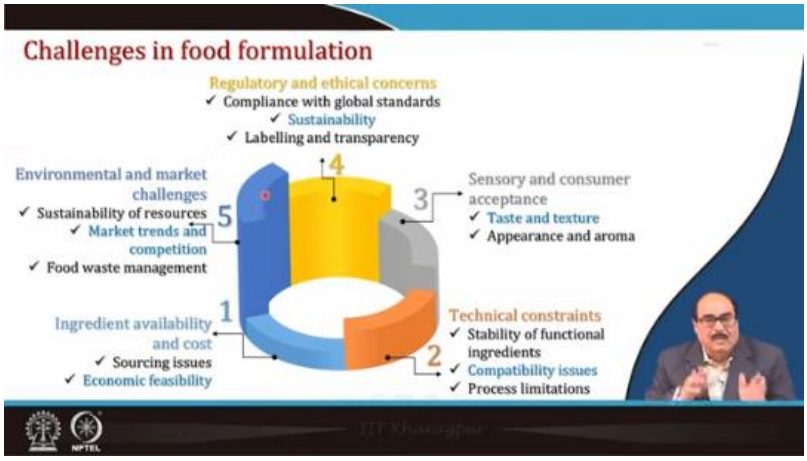
So, you have to evaluate the product characteristics like its structure, sensory etcetera, conducting microbial safety and storage stability test etcetera. at the prototype level or pilot scale level.



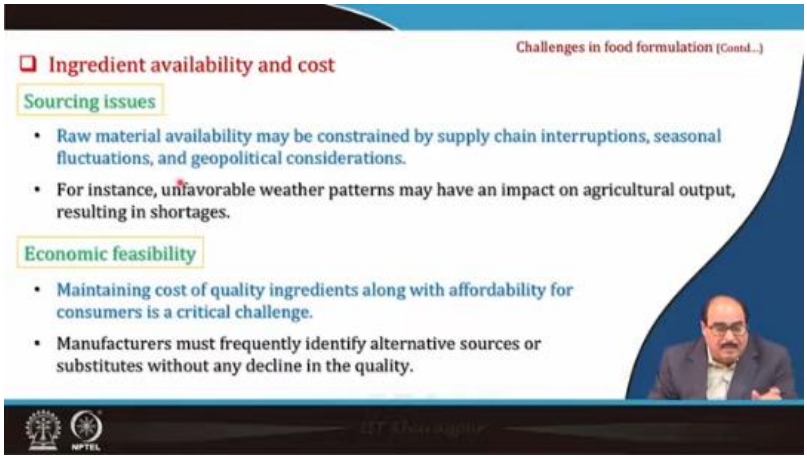
Like in the consumer testing adjusting the formulation based on preliminary trials ensure the product meets the nutritional, sensory and economic standards. Using the techniques like hedonic scale, quantitative descriptive analysis and standards or statistical methods like ANOVA or preference mapping, one should analyze the sensory data and finally, take a decision and then also if the need be depending upon the situation refine or adjust the formulation based on the sensory data and other insights, like that is you have to see that is a refinement that is whatever optimization you have got and the laboratory scale then it may change when you go for the pilot scale and then finally, when you go for the further large scale then this also after the sensory testing.

Then, it comes the upscaling that is after the pilot scale is ok, then you go for the industrial scale upscale do necessary calculation have proper equipment to the size machinery plant size etcetera. Adjust the formulation based on the preliminary trials ensure that the products meet the requirements, and other requirements, adjust the

industrial machinery to maximize output with minimum losses and automation of process operations with consistency should be performed. And then again here one must go for the quality assurance that developing protocols for quality analysis of raw materials and products, or ensuring compliance with the regulatory and safety standard because from here you are sending your material to the directly marketer to the consumer.



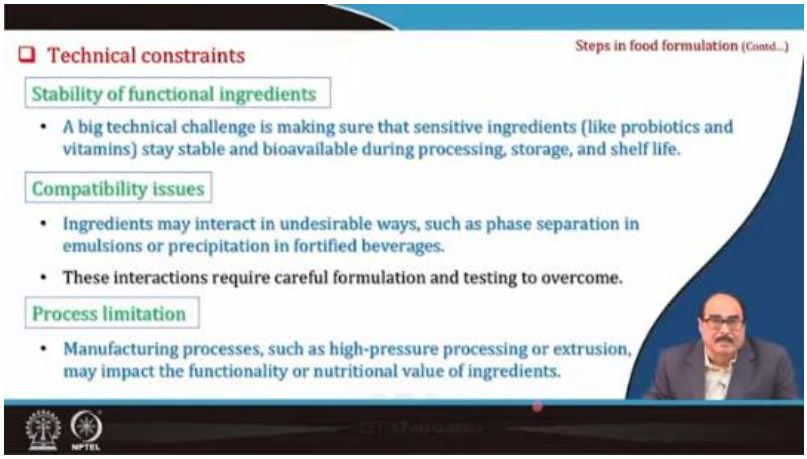
Then let us discuss what are the major challenges in the food formulation like there are challenges include ingredient availability and the cost. There may be technical constraints, even sensory and consumer acceptance, regulatory and ethical concerns and finally, the environmental and market challenges. So, these might be some important challenges in the food formulation.



Let us little bit elaborate like ingredient availability and the cost. Sourcing issues like raw material availability may be constrained by supply chain interruptions, seasonal fluctuations, and geopolitical considerations. For instance, unfavorable weather pattern

may have an impact on the agricultural output resulting in the shortages of the raw material. So, this becomes sometime a challenge that how to continuously supply the ingredients or raw material for the continuous production process.

Even the economic feasibility, maintaining the cost of quality ingredients along with affordability for consumers is a critical challenge. Manufacturers must frequently identify alternative sources or substitutes without any decline in quality.



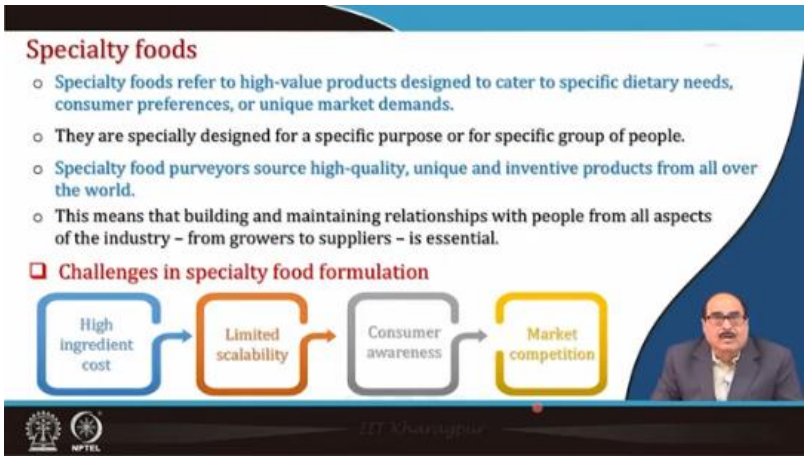
Then, technical challenges like ensuring that sensitive ingredients like probiotics and vitamins, etc., stay stable and bioavailable during processing, storage, and shelf life. So, the stability of functional ingredients is again a major technical constraint.

Compatibility issues like ingredients may interact in undesirable ways, such as phase separation in emulsions or precipitation in fortified beverages, etc., may take place. So, these interactions require careful formulation and testing to overcome them, and then process limitations like manufacturing processes such as high-pressure processing or extrusion may impact the functionality or nutritional value of the ingredients, etc.

Then, sensory and consumer acceptance like formulation of the product with less sugar, fat, or salt often affects the taste and mouthfeel. Thus, deterring consumers, achieving natural colors and flavors while ensuring stability is particularly challenging in clean-label products. So, that again becomes, many times, because the final product's sensory characteristics and what consumers want, how it will be accepted by consumers, etc., are not, and that requires a delicate balance of ingredients and given process parameters, etc., and that again is a great challenge many times.

Even then, regulatory compliances, regulatory issues, compliance with standards, regulations, policies, law, requirement, rule etcetera many a times there might not be the proper guidelines etcetera. So, industries definitely a phase this time this becomes a sometime a challenge to the product formulation and design. When for example, you are you are getting its proper ingredient you have to is make sure that whether there is a proper standard or it is with within the standard is within the limit etcetera or not.

Then, environmental and market challenges like sustainability of resources, reliance on limited resources such as water or land, intensive agriculture presents a sustained challenge. Then market trend and competition, fast shifting consumer tastes and intense market rivalry need flexibility in product invention and adaptation. Even one area of continuous focus is cutting waste during manufacturing and proto processing by means of efficient use of byproducts. So, therefore, that is a for the circular economy for a proper use of resources, food waste management is again a very good vast challenge and must be taken care of.



Now, talk about specialty foods. That are specialty foods refer to high value products designed to cater to specific dietary needs, the consumer preferences or unique market demands. These are especially designed for a specific purpose or for a specific group of the people. A specialty food purveyors source high quality, unique and inventive products from all over the world to make sure that their foods are having the desired specific

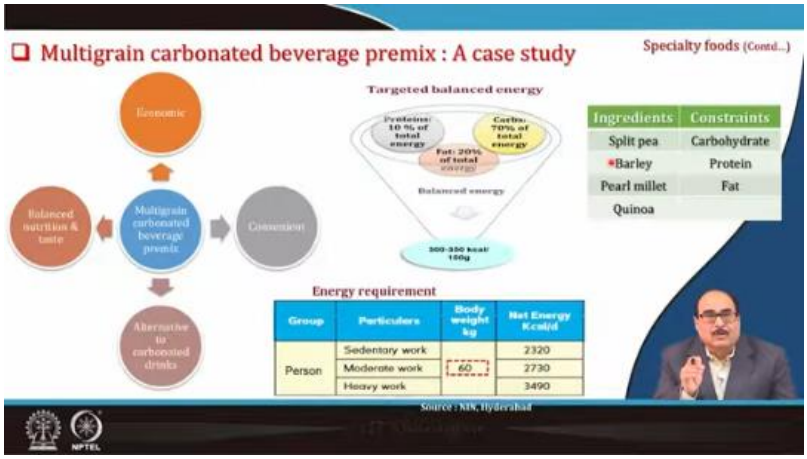
characteristics, specific ingredients etcetera. This means that building and maintaining relationship with the people from all aspects of the industry like from grower to supplier is essential in making a specialty food. So, the challenges in specialty food formulation again maybe there is one is the high ingredient cost because there is the for health food for high value food etcetera. So, ingredient also you have to get extra quality very high-quality material.

So, it obviously, the it may involve cost. So, high ingredient cost, limited scalability many a times, consumer awareness and market competition. These are the some of the challenges in the specialty food formulation.

The specialty food market is classified on the basis of product type, like for example, there will be cheese and plant-based cheeses etcetera, dairy cheese and plant-based cheese. Now, even frozen and refrigerated meat, poultry and seafoods, chips, pretzels or snacks, bread and baked goods, chocolate and other confectionery. So, they can be classified on the basis of the product type. And also, these specialty foods may be classified on the consumer generation that is Gen Z, Millennials, Gen X, Baby Boomers and so on. Or even, nowadays on the distribution channel like food service it is for the retail use or online market etcetera and so on.

So, the global food market for that a specialty food is increasing, it is increasing with a CAGR of 12.3 percent annually that in 2023. The specialty food they had a global market of 232.04 billion US dollar which rose to 264.68 billion US dollar in 2024. And, it is

projected that by 2028, the specialty food global market will reach to 420.79 billion US dollars, that is the business research consistency has projected this data.

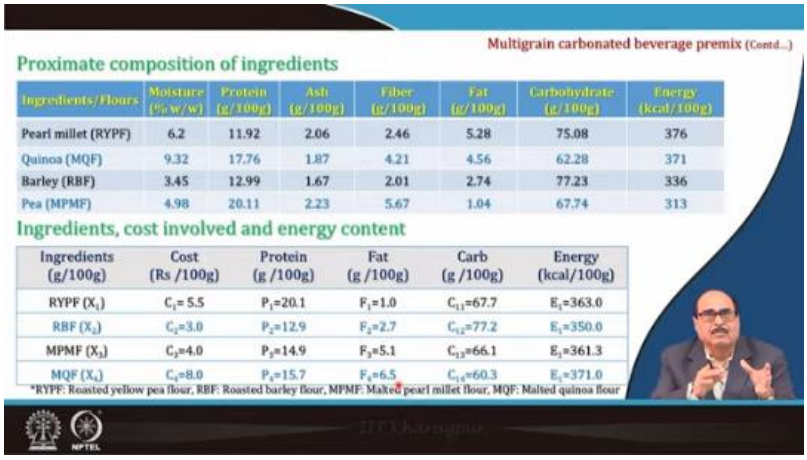


So, we will take a case study upon specialty food like multigrain carbonated beverage premix a case study. Here there is some this was research done in my laboratory where the purpose was to have a multigrain carbonated beverages premix. And it is a convenient product to use; it becomes an alternative to carbonated drinks, etcetera. It has balanced nutrition and taste, and, of course, economic value. So, it means the carbonated grain beverages are the market we wanted to produce this for. So, what is here is that it should have a balance, that is, the proteins should provide 10 percent of the total energy. You know, the balance of energy from carbs should come to 70 percent, and from fats, around 20 percent.

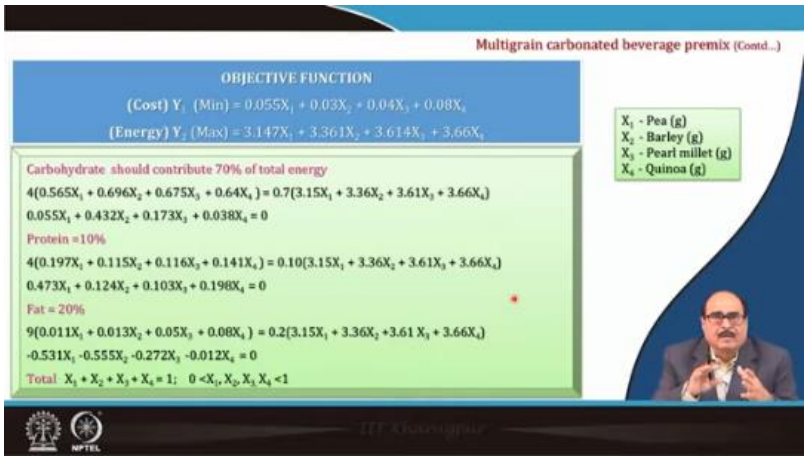
So, that was the target here, that is, in the energy you are getting. So, the various sources it contains ensure that whatever is needed comes. Finally, 300 to 350 kilocalories per 100 grams is what it provides. So, the contribution to the energy from the protein, carbohydrate, and fats. So, this becomes one criterion for deciding these gradients.

Then the ingredients were chosen accordingly, split pea, barley, pearl millet, and quinoa, which can provide all the carbohydrates, fats, and proteins, etcetera, and the content, obviously, carbohydrates, fats, and proteins from this. So, our job is to find out how to have a formulation in such a way that we decide how much carbohydrate, how much protein, and how much fat should be provided from all these ingredients. And the energy requirement, based on body weight per kg for moderate work, it gives 60 kg here.

So, it is 2730 as per the NIN, that is, these are the energy requirements for the different types of persons: sedentary work, moderate work, and heavy work. So, accordingly, these are the considerations in our formulation, in our design, etcetera, and we go for that. So, how we are proceeding is that we have selected that this, whatever material there is, we either analyze it in the laboratory or take it from suitable literature which is available. What are the various components present in this, like pearl millet (RYPF), quinoa, barley, and pea?



We have what is the moisture content, protein, ash, fiber, fat, carbohydrate, and total energy value. Then, for all these ingredients, what is the cost? And as per the protein, fat, carbohydrate, you know, you can calculate the cost and then the total energy. So, this information, on the basis of the ingredients that we have, we generate this information, all right.



And once this information is generated, either by calculations or by laboratory analysis or by taking help from the literature, etcetera, then we go for the programming, optimization, and analysis, that is, we take, maybe in this case, we use linear programming or here, with different equations, we used and decided that our objective was that the cost of the product should be minimized, and the energy content, that is, you get maximum energy with the minimum cost, and accordingly, that is,

$$(\text{Cost})\ Y_1\ \ (\text{Min}) = 0.055X_1 + 0.03X_2 + 0.04X_3 + 0.08X_4$$

and similarly, for energy also, and their equation is Y2, and their equation is calculated.

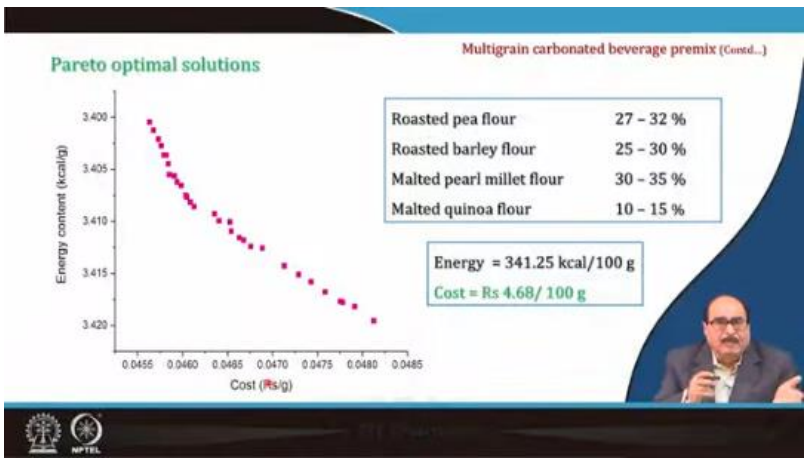
And these equations were found, that is, we decided this and put them into the solver in the computer program. And this will be used, and we have provided the input that carbohydrates should contribute 70 percent, protein 10 percent, fat 20 percent, and finally,

$$\text{Total}\quad X_1 + X_2 + X_3 + X_4 = 1$$

$$0 < X_1, X_2, X_3, X_4 < 1$$

So, these are the constraints you set, the limits, etc., what are the optimization functions, and decide the equations, etc.

And then it will give you a formulation required, it will run the program, and you will get the result like here.



The optimal solution we got from this is that you can see here in the chart, that is the energy content. Once you are getting the cost high, then the energy is also high. So, if

you are getting the energy content, higher the energy content, the cost also becomes high. The more energy you get, the more cost is involved. So, finally, our product with that optimized solution was roasted pea flour about 27 to 32 percent, roasted barley flour 25 to 30 percent, pearl millet flour in 35 percent, and malted quinoa flour 10 to 15 percent. Of course, there is some optimum range, I have given because of obvious reasons. So, in this now, once it is prepared, it will give the product with 341.25 kilocalories per 100 grams, and the cost will be 4.6 rupees. Of course, this is an indicative cost; it may vary depending upon the ingredient local cost, facility, etc.

But the purpose is by saying that once you get this optimum solution, then you go and manufacture the product prepare the product accordingly and then test it and you see this. So, that is just one example I have shown you to make you clear that is how should we go for the product preparations and other things.

So, finally, we can say that these food products are basically designed to meet consumer needs for taste, nutrition and sustainability. The principles like understanding raw materials, ensuring regulatory compliance and optimizing consumer centric designs are pivotal.

Steps in food formulation include there is development, ingredient selection, preliminary trials, prototyping and upscaling. And you must select that is and there are various challenges in every stage like in the formulation stage like challenges in the food formulation may include availability, technical constraints like stability and compatibility issues, consumer acceptance challenges related to sensory appeals and so on.

Similarly, specialty foods are high value products targeting specific dietary needs or preferences like gluten free, organic food, for foods for diabetic persons, food for older people, food for cardiovascular diseases etcetera.

So, in this formulation and design what is the things finally, you first decide that is yes what is what is your hypothesis, what you want actually in your product and for that you have to go for select different thing that is you have to conduct survey, you have to see what consumer wants. What are the resources available at your hand that is engineering resources, financial resources, materials available in the locality, preferences. So, basis on these things you go and design and have your products prepared and when particularly you are having a product. a specialized food for a specific purpose, then because all these foods for example, a diabetic food if you are going for at least that in that diabetic food it should have some either a is resistant carbohydrate or it should contain certain component which can regulate the insulin production etcetera. So, accordingly you have to select the ingredient in proper proportion, you have to formulate it and then select a process in such a way, so that you write that test during processing, during handling these those bioactives, the functionalities of those ingredients remain intact and accordingly suitable leveraging that is.

So, you can also calculate what are the possible losses during the manufacturing process. So, that also should be taken in your formulation initial calculation etcetera overages must be considered. So, finally, on the basis of all these things you go and have a product. So, this is what in the, but again the purpose here is that is one should have a systematic approach for the product designing, for the formulating the product. and implementing your design in your formulation and it should be on the based on the scientific approach proper technological sound backing and with also have a good equipment and processing property.

So, that processing packaging aim is to deliver the product to the consumer what he/she wants. So, with this may be details of this further with formulation what are the mathematical tools etcetera we will take up in the next class how to design with a few examples.

So, these were the references used in this lecture this.

Thank you very much for your patience hearing. Thank you.