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REVIEW PAPER

Meat Analogues: Plant based alternatives to meat products-A review

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Abstract

A meat analog, also called a meat substitute, mock meat, faux meat or imitation meat, approximates certain aesthetic qualities and chemical characteristics of specific types of meat. The consumption of vegetable proteins in food products has been increasing over the years because of animal diseases, global shortage of animal protein, strong demand for wholesome and religious (*halal)* food, and economic reasons. A meat-based diet requires a significantly greater amount of environmental resources per calorie compared to a more grain-based diet i.e. 2 to 15 kg plant foods are needed to produce 1 kg of meat. Developing new food products that are attractive to the consumers is a challenge. However, it is even more complex when these new foods are meant as a substitute for products that are highly appreciated and accepted, like meat. This challenge was accepted to develop new sustainable meat substitutes to reduce the negative environmental impact of industrial-scale meat production for human consumption. Happily there is an increasing importance of legume and oilseed proteins in the manufacturing of various functional food products due to their high-protein contents. However, the greatest obstacle to utilize these legumes and oilseeds is the presence of antinutrients, though these can successfully removed or inactivated by employing certain processing methods. Legumes and oilseeds provide well-balanced amino acid profiles when consumed with cereals. Soybean proteins, wheat gluten, cottonseed proteins, and other plant proteins have been used for preparation of meat anlogues successfully. Texturized vegetable proteins can substitute meat products while providing an economical, functional and high-protein food ingredient or can be consumed directly as a meat analogues. Meat analogues are successful because of their healthy image (cholesterol free), meat-like texture, and low cost. Mycoprotein a meat analog is fungal in origin and is used as a high-protein, low-fat, good texture and health-promoting food ingredient. Texturized vegetable proteins and a number of mycoprotein based products are accepted as analogues food. These are some constrains also in the production and consumption of meat analogues. Further research however is required to optimize molecular, nutritional, and functional properties of alternative protein sources to meat and to spread out the current knowledge to encourage the beneficial effects of alternative protein sources, as outlined in this review.

Keywords: Meat Analogue, legumes and oilseeds, Antinutrients, Texturized vegetable protein, Soybean proteins, wheat gluten, Mycoprotein

Meat is considered as the highest quality protein source not only due to its nutritional characteristics especially proteins but also due to its appealing taste. The role of meat proteins is two-fold. On one hand, meat proteins have all the essential amino acids closely resembling the human body (Xiong, 2004) that, make them highly nutritious. On the other hand, the meat proteins greatly contribute to the growth and development of food industry by imparting specific functionalities to the product. The principal protein functionalities in processed meats are gelation and related properties (for example, meat particle binding and adhesion, emulsification, and water-holding capacity. Among the commercial proteins used in the food industry, gelatin has been regarded as both special and unique, serving multiple functions with a wide range of applications in various industries.

Meat Analogue

Vegetarian foods occupy a larger than ever shelf space in today's market due to the consumers' increasing health concerns (Craig, 2010; Istudor *et al.* 2010) and the related environmental issues. Analogue can be defined as the compound that is structurally similar to another but differs slightly in composition. Here the meat analogue is the food which is structurally similar to meat but differs in composition. Meat analogue, also called a meat substitute, mock meat, faux meat, or imitation meat, (Sadler, 2004), approximates the aesthetic qualities (primarily texture, flavour, and appearance) and/or chemical characteristics of specific types of meat. It may also refer to a meat-based, healthier and/or less-expensive alternative to a particular meat product. Generally, meat analogue is understood to mean a food made from non-meats ingredients, sometimes without dairy products and are available in different forms (Table 1). Generally, meat analogues are made from soy protein or gluten.

Table 1: Common forms of meat analogues

Coarse ground-meat analogues	Emulsified meat analogues	Loose fill
Burgers	Deli 'meats'	Taco fillings
Sausages	Frankfurters	Chili mixes
Batter/breaded nuggets	Spreads	Sloppy Joe
Meat' balls		
Pizza toppings		

Functions and sources of Meat analogue

The main function of meat analogues is to replace meat in the diet. The market for meat analog does not only includes vegetarians but also the non-vegetarian seeking to reduce their meat consumption for health or ethical reasons, and people following religious dietary laws, such as *Kashrut*, *Halal* and Buddhist. Some meat analogues are based on centuries-old recipes for wheat gluten, rice, mushrooms, legumes, tempeh, or pressed-*tofu* (Table 2), with flavouring added to make the finished product taste like chicken, beef, lamb, ham, sausage, seafood, etc. They can be used to reduce formulation cost because they are cheaper than meat. Other attributes such as the ability of retaining water and moisture during cooking, reheating, freezing, and thawing makes them highly appreciable. Texturized vegetable proteins (TVP) are commonly used to provide the desired quality, texture, binding ability and desired amount of chewiness, or to make a product firmer or softer (Riaz, 2005). There are many health benefits of meat analog consumption over the meat such as protection against heart disease, lower blood cholesterol, reducing the risk of cancer and increasing bone mass (Sadler, 2004). Food scientists are now creating meat alternatives that truly taste like meat and have the same "mouth feel" their nature-made counterparts.

Table 2: Major nonmeat protein sources suitable for meat analogue

Type of protein	Sources	References
β-conglycinin	Soybean	Sun *et al.* (2008)
Glycinin, Vicilin	Legumes	Kang *et al.* (2007)
Legumin, Albumins, Globulins Glutelins	Oil seeds	Marcone (1999)
Gluten Gliadins Glutenins	Wheat, rye, and barley	Green and Cellier (2007)
Mycoprotein	*Fusarium venenatum* (Filamentous fungus)	Denny *et al.* (2008)

All this innovation could be great news for all those concerned about the health problems related to over consumption of fat, salt and cholesterol. There is also a need to look for new ways to raise nutrition for the poor at a minimum cost. Fortunately, there are thousands of plant proteins in the world, and many of them have yet to be explored for use in the production of meat alternatives. Current investigations of the world's vast array of plant proteins can fundamentally reshape our food supply for the better. The researchers are hopeful that they would be able to meet the demand for a protein-rich diet in a new way. All these aspects have briefly been reviewed in this paper.

Driving forces for the development of meat analogues

The increase in consumers demand for healthy diets, the concern about rising meat prices, the increase in the popularity of vegetarianism and the growing consumer interest in related eating patterns such as the avoidance or reduced consumption of red meat have resulted in a continuous increase in demand for the mean analogous and to use an alternative source such as the plant protein as the ingredients in the human diet.

At the beginning of 2010, an estimated 27 billion animals were domesticated as livestock globally, with 66 billions slaughtered each year around the globe (Schlatzer, 2010). This exceeds the number of human inhabitants on the globe. Global meat production has doubled between 1980 and 2007 from 136.7 to 285.7 million tons, egg production rose by 150 per cent from 27.4 to 67.8 million tons, while milk production has risen from 465 to 671.3 million tons (FAO, 2009b). If no provisions are made to avoid further growth in the livestock sector, meat production is forecasted to rise to 465 million tons by 2050 and milk production to 1043 million tons (Steinfeld and Gerber, 2006), due to the growth of global population as well as a forecasted increase of per capita consumption of meat and milk (Fig. 1). Nutritional transitions in developing countries especially emerging markets, such as China towards much higher intakes of animal derived foods, further aggravate the global problems associated with the increase in the demand for livestock products.

The nutritional value of meat products is mainly due to their high biological values of proteins, vitamins and minerals. However, from a health point of view, an excessive intake of meat products cannot be recommended. It is well known that meat contains cholesterol and a higher proportion of saturated fatty acids than polyunsaturated fatty acids (PUFAs) where is linked with several diseases which have reached epidemic proportions.

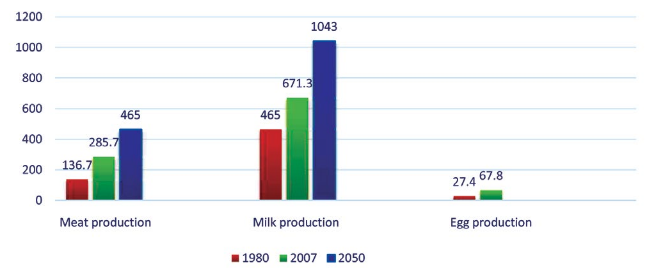

Fig. 1: Global trends in production of meat, milk and egg (million tons)

Furthermore, meat is the most costly resource form of food because livestock waste most of the energy and protein value of their feed in digestion and body maintenance. More food can be obtained by using land to grow crops for direct human consumption. A meat-based diet requires a significantly greater amount of environmental resources per calorie compared to a more grain-based diet as it has been estimated on an average 2 to 15 kg plant foods are needed to produce 1 kg of meat (Aiking *et al.* 2011; Fig. 2).

Meat is the first preference by choice of non-vegetarian consumers worldwide as it satisfies all the urges to consume one typical textured, flavourful, juicy, chewy food which will fulfil their nutritional requirements too. Presently, meat consumption in industrialised countries exceeds the required amount, considerably (Europe: 66.2 kg per capita per year in 2010-2012; Walker *et al*. 2005). But from the very beginning, meat has always been tagged with earlier discussed negative impressions with it. Sometime the reason is ritualistic, other times it is the question of healthiness stating to as an environmentally unfriendly food choice due to an inefficient use of land and energy, and emission of gases by meat production (McMichael *et al.* 2007). Policy makers and the organizations involved with sustainable consumption and production are hoping to see consumers making a shift to a more sustainable product.

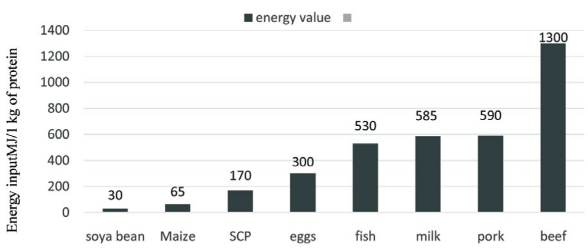

Fig. 2: Energy input in mega joule to produce 1 kg of protein (adopted from, Seiler, 2006)

Furthermore, animal proteins are scarce in many undeveloped countries and protein-energy malnutrition is among the most serious problems faced by the developing countries today (Boye *et al.* 2010). Due to several animal diseases, such as mad cow disease, global shortage of animal protein, a strong demand for "healthy" (cholesterol free and low in saturated fat), and religious (*halal*) food, with low cost, there is a strong pressure for the direct consumption of vegetable proteins in food products. Some even see the potential for a quite rapid end to the meat economy because of rising vegetarianism due to the influence of the animal rights movement (Asgar *et al.* 2010)

To overcome this entire dizzy situations, food scientists have invented one easy and innovative way formulating "meat analogue", which could accomplish the satisfaction of meat consumption and at the same time could provide the nutritional and health benefits equivalent to meat as well. All the informed opinions stress the desirability to reduce the consumption of animal products and increase intake of fiber-rich carbohydrates, plant based proteins and fresh fruit and vegetables in order to minimise risk of heart disease, mature onset diabetes, obesity and (possibly) some cancers also.

Various base foods used as meat analogues

Soya meat /Textured vegetable proteins (TVP)

Textured vegetable proteins (TVP) are generally, those fabricated vegetable products that can be used to replace meat completely in a food serving. These textured plant protein resemble meat in chewiness and flavor (Siddique, 2000). However, the transition from animal protein to plant protein can be possible only in a gradual, smooth and orderly fashion by utilizing high protein mixture, isolated protein and concentrated proteins from plant sources. Although most of the vegetable proteins are of inferior quality compared to the animal protein but legumes are good source of protein containing about 25-50% protein (Siddique, 2000). For the production of textured vegetable protein (TVP), beans are washed and soaked in water at 30°C for about three hours, so as to soften the husk and to remove a majority of anti-nutritional factors present. The soaked beans are washed with water until the husk is completely removed and then, dried at 70°C for 5-8 h (Riaz, 1999).

Soya meat, or textured vegetable protein (TVP), is produced from soy beans primarily in Asian countries. The production method is somewhat laborious but, the end product has a fibrous consistency similar to that of meat. With different seasonings a great variety of flavours can be achieved. Soya meat is extremely rich in protein with a protein content over 50 per cent, but the protein content drops when TVP is rehydrated. TVP has been developed in the USA and was introduced to the European market in the late 1960s, though with modest success (Vijver, 2006). But it should be noted that the quality of TVP has improved for the last 40 years. TVP is produced using hot extrusion of defatted soya proteins, resulting in expanded high protein chunks, nuggets, strips, grains and other shapes, where the denaturated proteins give TVP textures similar to the meat. The fibrous, insoluble, porous TVP can soak up water or other liquids a multiple of its own weight. Textured soy proteins (TSP) are processed to impart a structure and appearance that resembles meat, seafood or poultry when hydrated. Soy protein products have become increasingly popular because of their low price, high nutritional quality, and versatile functional properties. Two important soybean protein products are soy protein concentrate (SPC) and soy protein isolate (SPI). SPC is an edible protein product with a protein content of at least 65% on dry weight basis, whereas SPI is a product with at least 90% protein on dry weight basis (Kolar *et al*. 2010).

Fig. 3: Textured plant protein meat analog (picture is a courtesy of futurefood.org)

Table 3: Different types of soy proteins along with their preparation and uses

Type	Preparation	Uses
Textured Flours and Concentrates	Thermoplastic extrusion or steam texturization of soy flours or alcohol/heat denatured concentrates. Composition is similar to the corresponding source material.	Many types of fibrous foods. ground meat products, poultry and seafoods.
Structured Concentrates	Processed through an extruder into different sizes and shapes.	Poultry, meats and seafoods.
Structured Isolates	Extrusion as above or by extruding a solution of the isolate into an acid-salt bath that coagulates the protein into fibers that are combined with binders to form fiber bundles.	Poultry and sea foods. Food anlogues.

Source: Kolar *et al*. 2010.

Currently, flash-desolventized solvent-extracted white flakes (typically containing 50% protein) are generally the starting materials for SPC and SPI preparation. Other soybean meals or flours besides white flakes may also be used as starting materials provided that the final products meet protein content specifications and demonstrate desired functional properties.

The important attributes of soy flour, soy protein concentrate and soy protein isolate which play a significant role in defining the functional properties of derived meat products from them, are represented in table 4. The greatest obstacle in utilizing these legumes and oilseeds for the preparation of meat analogues is the presence of antinutrients, which can be successfully removed or inactivated by employing certain processing methods (Arntfield, 2009), prior to texturising.

Table 4: Meat analog favoring characteristics of textured soy products

Attributes	Soy flour	Soy concentrate	Soy isolate
Flavor	Moderate to high	Low	Low
Retort stable	Yes	Yes	Yes
Flavor development on retorting	High	Low	Low
Flatulence	Yes	No	No
Form/shape	Granules or chunks	Granules or chunks	Fibers
Cost (dry basis)	Low	Low	High
Recommended hydration level	2:1	3:1	4:1
Cost of hydrated protein	Low	Low	High
Fat retention	Moderate	High	Moderate
Optimum usage level in meat extension (% hydrated level)	15-20	30-50	35-50

(Adopted from: Malav *et al*. 2013)

Quorn–the mycoproteins

The process of bringing mycoprotein into the market place began long before the first product was marketed in 1985. However, the decision to develop a meat substitute based on fungal mycelium was taken by the British company Rank Hovis McDougall (RHM) during the 1960s and was followed by more than 15 years of research, development and toxicity testing before approval for the sale of the new food product was obtained from the British Ministry of Agriculture (Angold *el al*. 1989). Because of its high fibre content, "Quorn" had been found to help decrease blood cholesterol levels and could encourage reduced energy intake (Turnbull *et al*. 1993 and Denny *et al*. 2008).

Quorn is the brand name for a line of foods made from mycoprotein (*Fusarium venenatum*). Quorn products takes the form of faux chicken patties, nuggets, and cutlets, as well as imitation ground beef. It springs from a single-celled fungus grown in large fermentation vats which is processed and textured to produce a food which can be easily mistaken for meat. Generally, the filamentous fungus is best chosen for the production of a meat substitute because it was believed that the mycelia could was impart a fibrous texture, comparable to that of meat, to the final product (Edelman *et al*. 1983; Fig. 4). To make a similar-product texture with mycoprotein, the fungal biomass was mixed with a binding agent such as egg albumin, flavoring agents, and other ingredients depending on the desired final products (Denny *et al*. 2008). After heating, the protein binder has been found to get converted into a gel that binds the hyphae together. Extrusion then result in products that have similar textural properties to those found in meat products (Rodger, 2001; Fig. 4 and 5)

Quorn products include steaks, burgers, chicken breasts as well as sliced meats and ready meals such as *lasagna*. Nutritional benefits arise from mycoprotein due to its chemical composition. The cell walls of the hyphae (cells) are the source of dietary fiber (chitin and glucan). The cell membranes have been reported to be the source of polyunsaturated fatty acids (PUFA's) while the cytoplasm as the source of high-quality protein (Rodger, 2001).

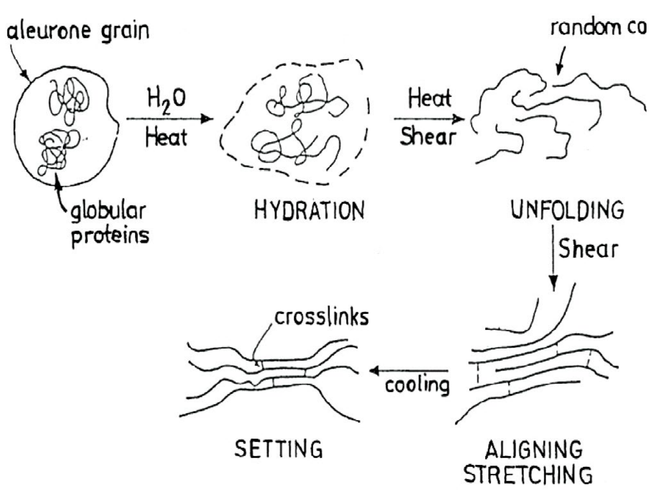

Fig. 4: Protein texturization mechanism

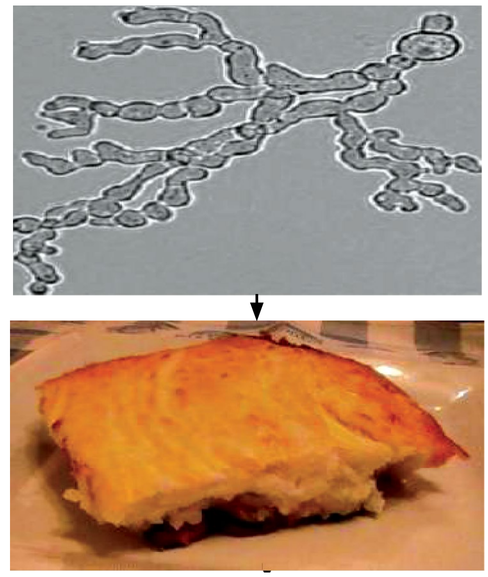

Fig. 5: Conversion of mycoprotein intoduring Extrusion Quorn mash pie

Source: M/s Marlow Food Ltd., United Kingdom.

It is cholesterol free and low in saturated fats with a favorable fatty acid profile and a fiber content that is comparable to other vegetarian protein sources. Furthermore, the essential amino acid profile of mycoprotein is comparable with other vegetarian and animal proteins.

Traditional fermented foods used as meat analog

Tofu

Tofu derived from soybeans is perhaps the most widely recognized meat alternative; it is an excellent source of protein, calcium, and iron. It is usually available in block form. '*Tofu*' prepared by coagulation of soymilk by $CaSO_4$ or $MgCl_2$ contains about 8% of total proteins, 4-5% lipids and about 2% of carbohydrates on fresh weight basis. *Tofu* has a special nutritional value due to the presence of dietary fibers (about 1%) and the absence of cholesterol, as well as a very low energety value (Sladjana *et al.* 2010). The high content of vitamins and minerals also contributes to the physiological value of the *tofu*. Early research on soybean composition documented that soybeans can be an alternative protein source in the human

Table 5: Comparison of essential amino acid content of mycoprotein and other protein foods (g amino acid /100g)

Essential Amino Acids	Mycoprotein	Cow's milk	Egg	Beef	Soy isolate	Soy concentrate	Peanuts	Wheat
Histidine	0.39	0.09	0.30	0.66	0.6	0.4	0.65	0.32
Isoleucine	0.57	0.20	0.68	0.87	1.1	0.8	0.91	0.53
Leucine	0.95	0.32	1.10	1.53	1.8	1.3	1.67	0.93
Lysine	0.91	0.26	0.90	1.60	1.4	1	0.92	0.30
Methionine	0.23	0.08	0.39	0.50	0.3	0.2	0.32	0.22
Phenylalanine	0.54	0.16	0.66	0.76	1.1	0.9	1.30	0.68
Tryptophan	0.18	0.05	0.16	0.22	0.3	0.2	0.25	0.18
Threonine	0.61	0.15	0.60	0.84	0.8	0.7	0.88	0.37
Valine	0.60	0.22	0.76	0.94	1.1	0.8	1.08	0.59

Source: Adopted from: Marlow Foods Ltd, 2008.

diet (Negata *et al*. 1998) with accumulated nutritional (Velasquez *et al*. 2007) and health benefits (Arjmandi *et al*. 1996; Azadbakht *et al*. 2007; Xiao and Chao, 2008). Soybean has a high content of Isoflavones linked to its improved nutritional value. The main isoflavones in soybeans are daidzein, genistein and glycitein. Isoflavones of soybeans exist in forms of aglycone, glycoside, malonyl glycoside and acetyl glycoside (Koudou *et al*. 1991).

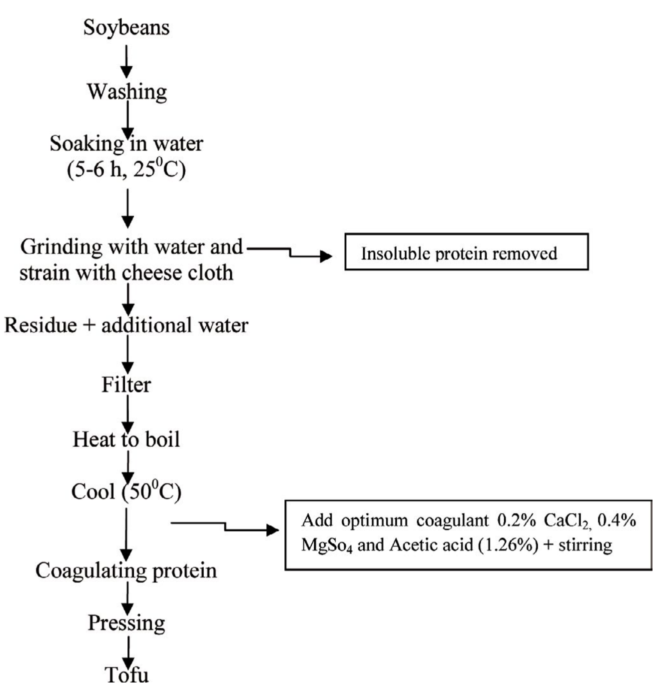

Fig. 6: Production technology of *Tofu* (Adopted from Bakshi *et al*. 2013)

Soybeans have been consumed traditionally in huge quantity over the world, especially in Asia. Soybean curd or *tofu* is a high protein product widely consumed in Asian countries especially among the vegetarians. It is, generally, made by protein coagulation of heated soybean milk with a coagulant ($CaSO_4$ or $MgCl_2$) followed by moulding and pressing the curd to drain the whey as shown in fig. 6 (Liu, 2004; Cai and Chang, 1999). *Tofu* is a jellied protein product with homogeneous composition and cream-colored with mild flavor. *Tofu* contains about 8% of total proteins, 4-5% lipids and about 2% of carbohydrates on fresh weight basis. *Tofu* special nutritional values due to the presence of dietary fibers (about 1%) and the absence of cholesterol, as well as a very low energy value. The high content of vitamins and minerals also contribute to the physiological value of the *tofu* (Wang and Murphy, 1994).

Tempeh

Out of indigenous fermented foods existing today; *tempeh* has been one of the most widely accepted mold-modified fermented products. *Tempeh* is a popular fermented food in Indonesia, rich in nutrients and bioactive substances. The consumption of *tempeh* has been increasing rapidly, not only in Indonesia but also in the United States and Europe (Babu, 2009). *Tempeh* is made from soybeans that have been soaked and cooked to soften them (Astuti *et al*. 2000). Like sour dough bread, *tempeh* requires a starter culture/inoculum (*Rhizopus oligoporus*), which is added to the cooked beans. This mixture is left for 24 hours and the result is a firm textured product with a somewhat nutty flavor and a texture similar to a chewy mushroom. *Tempeh* **i**s firm so it can be formed into a patty, it is used as a substitute for animal products what in the West is typically called as "mock meat" (Nout and Rombouts, 1990). Fermented soybean cake, or 'tempeh', is an excellent low-cost source of protein, having on an average of 19.5% protein, which compares very favorably with chicken (21%), beef (20%), eggs (13%), and milk (3%) (Shurtleff and Aoyagi, 2001). With the action of protease enzyme produced by mould during the fermentation process, the soluble protein content in *tempeh* increases sharply, making it more digestible than unfermented soybeans (Astuti *et al.* 2000).

Tempeh has the necessary characteristics of a dietary staple that is high in protein, fiber and is rich in other nutrients. It also has the advantage of containing Vitamin B_{12}, which is a by-product of the fermentation process (Irene *et al*. 1977). *Tempeh* is commercially available in the strip and cake form and is used in similar culinary contexts as *tofu* as it has a denser, "meatier" texture.

Tempeh is the result of mixed culture fermentation by a diverse group of microorganisms including moulds, yeasts, lactic acid bacteria and different gram-negative bacteria (Steinkraus *et al*. 1983) but *Rhizopus oligosporus* is the dominant tempeh fungus (Sharma and Sarbhoy, 1984). However some other moulds, such as *R. oryzae* and *Mucor* spp, may also contribute to its flavour, texture or nutritive value (Wiesel *et al*. 1997). Although the principal step in making *tempeh* is the fermentation of soybeans by *Rhizopus* mould, many other factors affect the success in production and the quality of the product. In the method employed by Steinkraus *et al.* (1960) raw, dried soybeans are hydrated by soaking in cold water overnight or for a shorter period of time if warm water is used. Lactic acid or acetic acid is added to the water to lower the pH of the solution and the soybeans to 5 or below. This step is performed to discourage growth of undesirable microorganisms (fig. 7). The *Rhizopus* mould is largely unaffected by the acidic environment. After hydration, the skin on each bean is removed to encourage better growth of the mould. The skinned beans are than partially cooked by boiling them in the acidic soaking water at 100°C for 90 minutes. When the beans have cooled to 37-38 °C, the ideal temperature to begin the inoculation and the beans have been dried, the *Rhizopus* starter culture inoculars added @ 1 gram per kg the beans (Hesseltine *et al.* 1963). The inoculated beans are then placed on covered trays, in a layer no thicker than 2 inches, so that sufficient oxygen be available on the bean surfaces for mould growth. Small holes in the trays would also be beneficial in ensuring sufficient oxygen supply.

In addition to oxygen, the mould grows better in high humidity levels (75-78%). However, no liquid water should be in contact with the beans (Farnsworth and Edward, 2008). The ideal temperature for *Rhizopus* growth is 37°C. During the phase of active mould growth, however, the temperature of the beans will naturally rise above the ambient temperature. Above 49°C further mould growth was inhibited (Han and Nout, 2000).

Kinema

Kinema is a non-salted, solid-substrate fermented, flavoursome, alkaline food, traditionally consumed mainly by the Nepalis, Lepchas and Bhutias. Fermentation is dominated by *Bacillus* spp. that often cause alkalinity and desirable stickiness in the product. Generally, the moisture content of kinema is 62%; on dry weight basis, kinema contained about 48% protein, 17% fat, 28% carbohydrate and 7% ash (Wang and Murphy, 1994). In the traditional method of kinema preparation, yellow seeded soybeans are cleaned, washed, soaked overnight (12-20 h) at ambient temperature (10-25°C), cooked by boiling (90-95°C) for about 90 min, crushed lightly to grit, wrapped in fern or banana leaves and sackcloth, and left to stand (25-35°C) for 1-3 days. The desired state of fermentation is indicated by the formation of a typical kinema flavour dominated by ammonia the production of ammonia is a consequence of the utilization of amino acids by the bacteria as a source of carbon and energy. Fresh kinema is briefly fried in oil and added with vegetables, spices, salt and water (Tamang *et al*. 1988; Sarkar *et al.* 1993, 1994; Sarkar and Tamang 1994).

Seitan

It is often known as "wheat meat" or "wheat gluten," is another common vegetarian meat substitute. It consists of the protein components gliadin and glutenin which are isolated from wheat by rinsing the

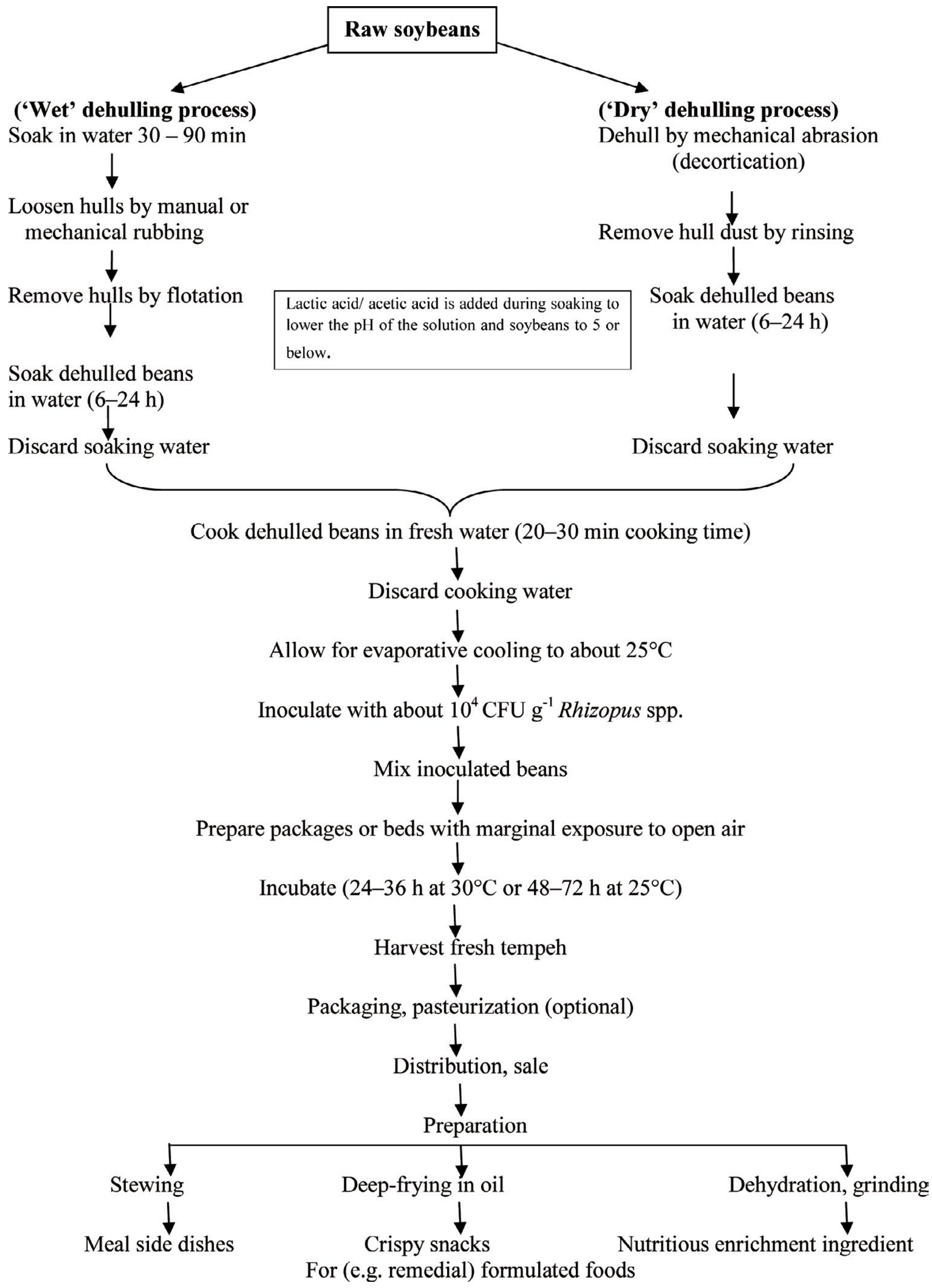

Fig. 7: Production technology of *"Tempeh"* (Adopted from Nout and Kiers, 2004)

wheat dough until the starch and bran components have been washed out resulting in a chewy mass. It is one of the most cost effective and simple raw materials for producing vegetarian sausages, burgers, nuggets, schnitzel as well as minced meat. In addition, wheat is a crop that is native to the majority of countries around the world. Thus, the production of *seitan* is possible on a global level. The consistency of *seitan* is remarkably similar to the stringy fibres that make up the consistency of meat (Schmidinger, 2012). *Seitan* can be seasoned and prepared in a wide variety of ways. In preparation, an appropriate reducing agent, protease, or glutathione can be added to cut the peptide linkages of the elastic wheat gluten according to the physical properties desired.

The water content of the mixture is adjusted within the range of 40 to 80 (w/w %), and the mixture is then, subjected to extrusion and can be extruded into a pipe or cylindrical or into a sheet through a nozzle provided with a slit, and is then, formed into a continuous sheet having a thickness of about 4 to 20 mm and breadth of about 100 to 1000 mm. The sheet is stretched at least 2.5 folds in the stretching process, whereby the fiber structure is endowed with directionality. The resulting sheet is transferred to the next heating process in airspace having relative humidity within the range of about 75 and the temperature of 75-120°C (Yoshioka *et a1*. 1986).

Fibers from lupines

The seeds of sweet lupines can be used for vegetarian meat production, too. Meatless (a product by the Dutch company Meatless BV) is made of 100 per cent vegetable fibers, made from lupine or wheat (Anon, 2015a). The fibers are produced in different shapes, flavours and colors. Meatless is used for meat-substitute products as well as for developing "hybrid products", which are meat-products in which a large portion of the meat is replaced by Meatless. There are also other lupine based meat alternatives on the market, but these have not entered relevant market segments so far.

Rice based products

US company Bahama Rice Burger produces rice burgers and sausages based on what they call "Risofu", a word derived from riso, the Italian word for rice, and *tofu*, meaning *tofu*. According to the company, it developed the product with inspiration from the Shan region of Thailand, where rice based '*tofu*' is made. Risofu mixes white, brown and wild rice to obtain as many nutrients as possible (Schmidinger, 2012).

Algae based product

Algae could also be a potential precursor of vegetarian meat alternatives, together with cereals, rice, edible oils and thickening agents. Small manufacturers in different countries offer such products like the Germans produce 'remis algen' (Anon, 2015b).

Major concerns related to direct use of plant proteins as meat analog

There are some major issues of concern related to the direct use of plant proteins to imitate the meat products from the market.

- One of the major disadvantage of soy protein is the strong off-flavors associated with the soy derived products. Two types of off-flavors one grassy and beany flavor (due to activity of lipoxygenases) and the other bitter and astringent flavour (due to saponins and isoflavones) that restricts the use of soy protein as meat analogues. However, germination, either alone or in combination with heat treatment could overcome this problems (Suberbie *et al.* 1981).
- Saponins and isoflavones were previously considered as undesirable substances being antinutritional, but are considered useful in a low concentration range because of their anticarcinogenic activities (Fukushima, 2004).
- A number of allergenic food proteins have been characterized in legume crops including soybeans, lentils, common beans, mung beans, chickpeas and peas(Singh and Bhalla

2008; Riascos *et al*. 2010). Protein inhibitors are important in determining the quality of legume seeds and their antinutritional effect in the irreversible inhibition of different digestive enzymes. The most characterized protein inhibitors are α-amylase inhibitors (Moreno *et al.* 1990) and trypsin inhibitors (protease inhibitors) (Domoney *et al*. 1993).

- Phytic acid present in legume seeds reduces the bioavailability of essential minerals by forming salts that are mainly excreted (Desphande and Cheryan 1984). This phenomenon leads to mineral depletion and micronutrient deficiency in humans. Gluten is the major protein found in cereals (wheat, rye, and barley) and is harmful to some individuals. Celiac disease (CD) is a disorder that is characterized by a permanent intolerance of gluten proteins in which the absorptive epithelium of the small intestine becomes damaged (Sadler, 2004).

These constrains have no doubted limited the use of these plant proteins for preparation of meat analogues. However, several strategies have been developed to overcome these problems. (Arntfield, 2009). Therefore, by utilizing one or other available technologies to remove or inactivate these antinutritional substances these abundantly potential plant protein sources can be utilized for the production of alternative meat products at much cheaper prices.

Economic aspects and future trends

An important reason for the increased acceptance of plant protein is their low cost and fibrous texture. The major challenging task for the food engineers however is to develop the fibrous three dimensional structure from these plant proteins while maintaining their nutritional properties so as to provide these alternate meat products the same meaty texture. Texturized wheat gluten is commercially available in several forms differing in size, shape, density, color, and texture. The popularity of texturized wheat gluten is rapidly increasing due to abundant production of wheat throughout the globe. The researchers are trying to develop wheat varieties that have a minimum amount of gluten while maintaining its technological properties. Genetic engineering can enhance the quality of plant based food products through the silencing of genes.

New plant based meat anlogues should taste, feel and smell better, or at least as good as animal meat according to the perceptions of the majority of consumers. It is very probable that flavor (umami flavor associated with meat) and texture (fibre like as in meat products) are the most important keys to success, and at the same time, the biggest challenges for the researchers.

It can be concluded that there is a demand as well as bright future of such products in the market keeping aside a few constrains which need solution but with a the heap of opportunities.

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