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Utilization of milk powders and protein concentrates in the formulation of novel composite cereal-based functional energy bars

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Abstract
Energy bars are a versatile and convenient snack option. They serve as convenient composite foods, potentially replacing meals, offering a compact, energy-rich solution with cereals as a major component. They are highly versatile snacks containing high-quality proteins, polyunsaturated fatty acids, minerals, vitamins, and fibers. Bars have witnessed a recent rapid growth in consumption. The popularity of energy bars is rising, with 90% of Australians regularly consuming them. The Indian market is experiencing significant growth, with energy bar sales increasing at a rate of 25% from 2018 to 2023, reaching diverse consumer groups, including athletes, children, and young adults. Energy bars typically supply 200–300 kcal energy, with varying levels of fat, protein, and carbohydrates. While they offer essential nutrients, attention must be given to potential drawbacks, such as energy density, fat content, and allergen information, emphasizing the importance of moderation and transparency. Various ingredients, including dairy-based components, contribute to the nutritional quality of bars. Plant and animal-derived sources yield bioactive compounds during digestion, making bars potential functional foods. The incorporation of specific ingredients can enhance health benefits and cater to specific consumer needs. Ultra-processed foods face challenges related to additives and potential health issues. In contrast, bars, especially those with natural ingredients, aim to provide a healthier alternative, emphasizing the importance of developing low-calorie, functional bars to meet diverse nutritional needs.

Keywords: Energy bars, novel composite cereal-based, milk powders and protein concentrates

Introduction
Bars are proportioned and convenient composite foods, widely consumed as a potential meal replacer for supplying nutrients in adequate quantities (Cabanilla *et al*., 2020) [5]. They are defined as a compact, energy rich, composite food in which cereals are in major amounts (Curtain *et al*., 2019) [11]. Bars are mainly consumed as snacks (Williams *et al*., 2006) [53] and dairy-based ingredients (such as MPCs and milk powders) can be potentially used in their formulation. Snack bars are highly versatile and confer nutrition (high-quality proteins, polyunsaturated fatty acids, minerals, vitamins, and fibers) in one convenient, easy to store and carry package. They can be classified as ready-to-eat formulations which are usually based on whole cereal grains, seeds, plants, and certain animal-based products such as dairy ingredients (Tanskanen *et al*., 2012) [47]. They contain many other components such as seeds, nuts, dried fruits (Rawat *et al*., 2015) [40]. Vitamins and minerals can be added to improve the nutritional quality (Mietus-Snyder *et al*., 2012) [29]. As of now, there are no standards established by FSSAI.

Ninety percent Australians regularly consume confections such as energy bars. The energy bar is an emerging snack in the Indian market. The sales of snacks in India has increased in value from being USD 2.14 billion in 2012 to USD 3.82 billion in 2016. Energy bar sales in India are growing at a fast rate of 25% over the forecast period, 2018-2023. The bars are targeted at all age groups, but specifically consumers with high energy needs such as children, adolescents, young adults and (Nadeem *et al*., 2012) [31]. There can be highly specific users such as gym goers, athletes, military personnel and space voyagers. They are rich in carbohydrates, proteins, and vitamins which are mainly derived from the ingredients

(Mridula *et al*., 2013) [30]. Certain ingredients yield bioactive compounds during digestion making bars a potential functional food (Weaver, 2014) [52]. However, bars are energy dense, hence should be consumed in moderation. (Hertzler *et al*., 2003) [20]. Fat plays a key role in making bars dense in calories, which needs to be minimized. Allergen information is also imperative to be declared regarding the presence of gluten, milk, soy, peanuts, and almonds (Valenta *et al*., 2015) [49].

Importance

Many firms in the processed-food industry are involved in manufacturing of cereal bars and snack bars whose use is prevalent among adolescents. Due to enhanced sensory (flavor, color, and texture) attributes, convenience (portability, shelf life and preparation time), and efficiency, the use of energy bars in the United States has rapidly increased owing to all these important food characteristics. Bars are portable and convenient to carry. Thus, they are useful in conditions where it is not possible to consume conventional foods. Potential applications can be highly specific such as for the military and space food. Apart from meal replacers, energy bars can be used as a dense and portable source of carbohydrates. They also provide proteins, which can yield bioactive peptides during digestion. These peptides possess specific functionality and can impart physiological benefits to the host. Highly physically active consumers such as athletes, can consume energy bars as a compact source of energy. Apart from this, people on diet and individuals with nutritional problems or irregular meals can also use energy bars for their nourishment, provided that the bars do not contain anti-nutritional factors and allergens that are deleterious for health.

Composition and Nutrition

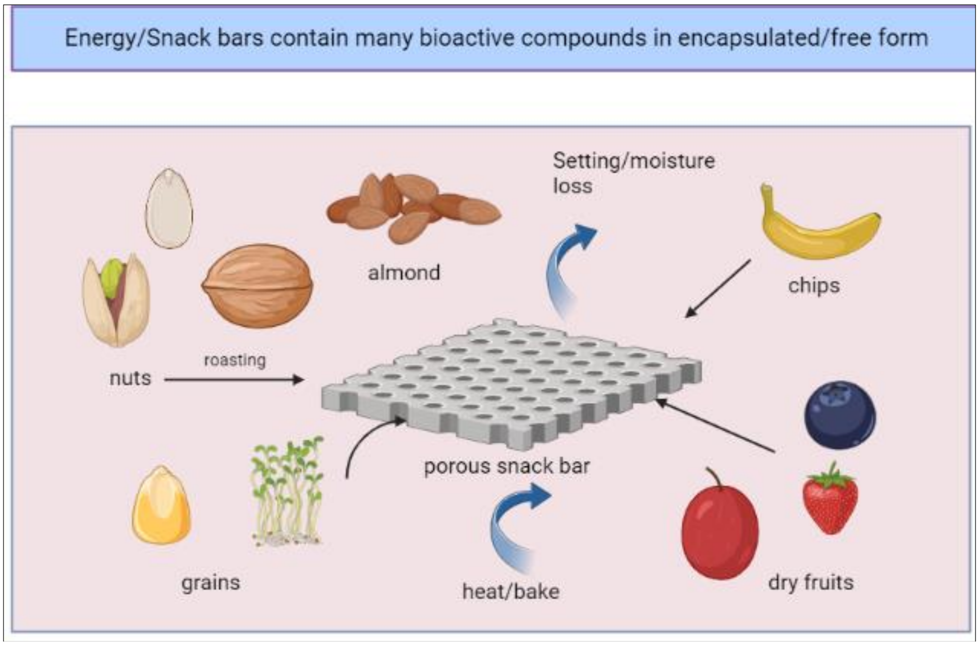

Fig 1: Process of formulation of snack bars from various ingredients

An energy bar (45 - 80 g) can supply about 200-300 kcal (840–1,300 kJ) energy. This generally contains 3-9 g fat, 7-15 g protein, and 20-40 g carbohydrates. As these bars also contain cereal-based constituents, they are rich in many phytonutrients known for their biological activity. Therefore, they can confer physiological benefits and can act as potential functional food. However, the risk of the presence of anti-nutritional factors is an issue of major concern (Gilani *et al*., 2012) [17].

Fat plays a key role in making bars dense in calories, which needs to be minimized. However, their content is more in case of protein bars as compared to energy bars in which carbohydrates level is prevalent. Complex carbohydrates are considered better than simpler. Although the fat, protein, and carbohydrates are the main source of calories, many bioactive compounds such as fatty acids and peptides can be derived from them. The degree of release of such components is associated with the composition of the proteins and fats. Snack bars can act as good carriers of healthy nutrients, bioactive compounds, and dietary fiber. Thus, it is an edible commodity that can be classified under the category of functional foods. Such foods are known to provide additional health benefits apart from original nutrients. This can be achieved by fortification and enrichment with other bioactive components derived from plant sources. Therefore, modifications in product formulations and the adoption of new technologies in processing have achieved a significant improvement in the nutritional quality of bars and also helped in meeting consumer requirements as well. Many bars are rich in nutrient such as total fat, trans fat, cholesterol, mono and polyunsaturated fatty acids, omega-3 and omega-6 fatty acids, saturated fat, vitamins (A, D, E, C), iron, calcium, phosphorus, sodium and potassium (Curtain *et al*., 2019) [11].

Processing of snack bars

Suitable treatments can be given to the ingredients such as roasting, size reduction, blending, mixing, irradiation, conditioning, puffing and washing. Constanin *et al.* (2018) reported three types of Energy bar production process (I, bars that were baked; II, bars that were filled and baked; III, bars made using cold process) The steps like mixing of dry and wet ingredients, moulding, baking, cooling and packing were reported.

Bühler Snack Fix Bar Production Process has following steps.

1. Mixing water and powder and heating up to 80 °C.
2. Filling the hopper with cereal mix.
3. Filling the prepared binder into the preheated vessel.
4. Starting the process.
5. Picking up products and storing them for some minutes.
6. Using the best cutting mould for the product.
7. Feeding the products into the flow wrapper and packaging them.

A method for making a granola or snack-food product comprises (a) mixing ingredients for said granola or snack-food product with liquid binder to obtain a formable mixture, wherein the mixing is carried out at elevated temperature and the binder is liquid at elevated temperature and the binder sets when cooled to room temperature; (b) forming the mixture into product precursor, wherein the forming is carried out at elevated temperature and whilst the binder is still liquid; and (c) cooling the precursor to set the binder, thereby obtaining the snack-food product. Apparatus for making the product is also described as is the product obtained thereby.

Drawbacks of other processed foods

Ultra-processed foods are largely composed of additives including synthetic colors, flavors, sweeteners, emulsifiers, and preservatives (Mridula *et al*. 2013) [30]. These can affect the food safety as well as quality. Therefore, many companies and product developers are working on formulating natural cereal-based functional composite bars which show functionality as well (Constantin *et al*., 2018) [15]. Frying, molding, and hydrogenation are some of the techniques which are commonly involved in the processing of such food products. The bars lack disease-fighting phytonutrients **(**Sun-Waterhouse *et al*., 2010) [46]. Moreover, bars containing partially hydrogenated vegetable oils might not be a healthy alternative since they contain saturated fat and trans-fat which are associated with many cardiovascular conditions (Pantazopoulos *et al*., 2011) [35]. High fructose corn syrup, sucrose and glucose syrups are rich in carbohydrates that act as suitable substrates for the growth of microorganisms responsible for causing dental caries. Therefore, it is imperative to develop wholesome, low-calorie and cost-effective bars while maintaining food quality using specific bio-actives that are important for providing functionality in novel food formulations (Cencin *et al*., 2010) [6]. However, sufficient processing of ingredients should not be overlooked to compromise food safety (Sanders, 1999) [42]. Apart from the basic nutrients (such as proteins and carbohydrates), components that impart functional properties can be incorporated in the composite food matrix to get desired physiological benefits (Lang, 2007) [22].

Common Ingredients

There are a number of important ingredients which can be used for making bars. Some of the widely used components include cereal grains, pseudo-cereals, pulses, whole-grain products, nuts, fruits, vegetables, dairy ingredients, syrups, vegetable fat, honey and sugar. Rice, wheat and oats are main cereals. Ingredients such as artificial intense sweeteners, colors, flavors, vitamins, minerals, Arabic gum, wheat germ, commercial coatings, glycerine, emulsifier, citric acid, and preservatives have also been reported to be used to a limited extent. Natural sweeteners provide flavor, consistency, integrity and firmness (Rippe *et al.*, 2013) [41]. Dry fruits like dates, raisins and cranberries; honey; corn syrup and glucose syrup are natural sweeteners. Artificial sweeteners may be sucralose and stevia. Antioxidants such as Vitamin E, plant extract such as rosemary extract are also added to improve the shelf life and taste of the product (Nieto *et al*., 2018) [32].

Potential ingredients for snack bars/ Valorization of non-dairy ingredients in manufacturing of bars

There are many potential ingredients that can be used in bars to impart functionality (Constantin *et al*. 2018) [15].

Amaranth is rich in phenolics and antioxidants. Oat is a good source of soluble fibre such as ß-glucan (Marais, 2017) [26]. Sorghum is rich in policosanols, tannins and 3-deoxyanthocyanidins (Cardoso *et al*., 2017) [12]. Brown rice is rich in tocotrienol, tocopherol, oryzanol, and amino acids (Ravichanthiran *et al*., 2018) [39].

Flaxseed is rich in omega-3 fats (Mridula *et al*., 2013) [30]. Seeds such as sunflower, pumpkin, chickpea, are rich in phytochemicals showing many medicinal properties (Guo *et al*., 2017, Veronezi *et al*., 2012) [18, 50]. Lentils are rich in polyphenolic compounds (Ganesan *et al*., 2017) [16]. Soy can yield bioactive peptides on protein hydrolysis (Chatterjee *et al*., 2018) [9].

Jeriva fruit pulp is rich in tocopherol, carotenoids, linoleic and oleic acids (Coimbra *et al*., 2012) [10]. Dates contain polyphenols that show activity against cancer and cell damage. Pear and apple are rich in antioxidants and lipids (Leontowicz *et al*., 2002) [23]. Acerola cherry is rich in flavonoids, anthocyanins, phenolics and ascorbic acid (Prakash *et al*., 2018) [37]. Banana is a good source of phytosterols, carotenoids and phenolics (Singh *et al*., 2016) [44]. Rose petals are associated with prevention of oxidative stress.

Chicha, sapucaia, gurgueia nuts are rich in lipids and tocopherol (Demoliner *et al*., 2018) [13]. Fig contain many volatiles and phenolics. Raisins are rich in antioxidants and antimicrobials (Abouzeed *et al*., 2018) [2]. Nuts and dried fruits are rich in carotenoids and many phenolics (Hernandez-Alonso *et al*., 2017) [19].

Fortification

Fortification of food with micronutrients is widely used particularly to meet the recommended dietary allowance (RDA) values as specified by the National Institute of Nutrition. Therefore, it is imperative to develop economical, protein-rich, micronutrient fortified bars, which can be better alternatives for protein rich supplements either derived from plants (such as soy) or dairy ingredients (such as protein concentrates and isolates).

Dairy Products as Functional Bar Ingredient

Milk powder, milk protein concentrates or isolates can release bioactive peptides during digestion (Park *et al*., 2015) [36]. From milk and dairy products, bioactive constituents such as antioxidants, peptides, proteins, conjugated acids, linoleic acid, vitamins, oligosaccharides, and organic calcium can be derived. These components provide health benefits such as improving hemodynamics, probiotic growth, GIT modulation, and immune-regulation (Park *et al*., 2015) [36].

Many bioactive compounds derived from plants and animal sources are able to provide antimicrobial, metabolism modulating, anti-obesity, satiety modulating, hypotensive and hypocholesterolemic effects (Rao, 2003) [38].

Milk powder

Milk powder based bars can meet nutritional requirements of the armed forces, especially in conditions where conventional food is not available. Low-fat milk powder can be a good source of protein. The milk proteins mainly consist of casein and serum proteins (also known as whey proteins), which yield many bioactive peptides during digestive hydrolysis (Chakrabarti *et al*., 2018) [7].

Plant ingredients also contribute to physicochemical and biological properties not imparted by dairy counterparts. This effect is associated with the presence of phytochemicals such as phenolic compounds. Coconut powder can provide dietary fiber while cacao imparts characteristic chocolate flavor and color. Lecithin emulsifies while butylated hydroxytoluene (BHT) is associated with preventing rancidity by lowering rate of fat oxidation. Therefore, this antioxidant can be used in bars to preserve the flavor profile. (Lin, 2016) [24].

Although, texture and color did not change significantly during storage, bar hardness increased which is correlated with moisture loss. This leads to concomitant decrease in water activity.

Standard plate count increased slightly from 2.64 to 3 log CFU/g after 6 months storage at 38 °C. The yeast and mold count increased to 1.67 log, which was within standard limit < 2 log for such products. *Salmonella*, *Enterobacteriaceae*, *Escherichia coli* counts can vary based on the source or quality of the raw materials used, which plays a key role in determining food safety of the formulated bars. Moreover, the peroxide value remained unchanged as well which indicates good stability against fat oxidation.

Milk protein concentrates/isolates (MPC/MPI)

Milk protein concentrate is categorized as a casein-dominant ingredient (Yada, 2018) which can be divided into low (≤ 42%), medium (60–70%) and high (≥ 80%) protein ingredients, while MPC with a protein content > 90% is generally termed milk protein isolate (MPI) (Agarwal, Beausire, Patel, & Patel, 2015) [2]. The casein to whey protein ratio (4:1) of MPC and MPI powders are similar to that naturally present in milk. MPCs are used as a replacement for skim milk powder (SMP)/non-fat dry milk, for protein adjustment of commercial products such as neutral pH ready-to-drink high protein beverages, ice-cream, Greek style yogurt, spreads, coffee creamer and whipping cream. They are also used in the formulation of protein fortified products, nutritional beverages and bars, in clinical nutrition, dietary supplements and sports/performance nutrition (Agarwal *et al*., 2015; Singh, Prakash, Bhandari, & Bansal, 2019; Chamberland *et al*., 2020) [2, 45, 8].

Studies on bars using Dairy Ingredients

Novel dairy-based functional foods can be formulated using MPCs since they are rich sources of protein. However, solubility characteristics are the most variable and need to be controlled to use the ingredient effectively in products such as in the preparation of bar mixtures, fillings, and coatings. Protein content and process parameters are the major factors affecting this property.

The insolubility of these dairy-based protein powders is governed by mechanisms that are necessary to be well understood. It is a well-established fact that solubility which also governs other functional properties is poor for MPC and MPI powders. Further, decrease in solubility of MPC/MPI powders is positively correlated with their protein contents. Different chemical, physical and enzymatic methods have been used by researchers to improve the solubility of MPC/MPI powder (Meena *et al*., 2017) [27]. These methods are capable in improving the functionality of novel product formulations and will act as a substitute for alternative ingredients like whey-based powders such as WPI and WPC. This can not only ensure quality but can also be promising for developing novel applications for the food industry while improving the functionality as well.

High-protein nutrition (HPN) bars (~20 g MPC/100 g) have a tendency to lose moisture and harden during storage that led to the loss of acceptability. (Kumar *et al*., 2018) [51] Bars containing MPI in formulation not only lacked cohesion but also had crumbly texture. This may be prevented by having control on the storage conditions. However, bars formulated using spirulina had the ingredient ratio adjusted that yielded a bar with lower hardness. Moreover, it did not lack cohesion and integrity as compared to those made with MPI. High protein nutrition (HPN) bars with extruded MPC80 showed slower hardening compared to bars formulated with unmodified MPC. Extruded MPC80 bars were significantly softer, less crumbly, and more cohesive than the control. However, the bars became firmer and less cohesive during storage (Banach, 2016) [3]. Therefore, it is imperative to have control over hardness as well to ensure consumer acceptability.

Conclusion

Energy bars are supplemental cereal-based foods that are formulated to target consumers requiring immediate energy and need replacing full-meals. Unlike energy drinks, energy bars do not contain caffeine, unless ingredients like coffee powder or tea extracts are incorporated. Nutrient bars, particularly protein bars, contain protein and carbohydrates in significant amounts, which can contribute to the presence of bioactive compounds apart from meeting the basic nutritional requirements. Therefore, researchers need to attempt formulation of low-calorie energy bars from diverse protein-rich ingredients to maximize the range of phytochemicals incorporated and to increase their bioavailability as well among adolescents. However, in developing countries meeting needs lower income can be achieved by formulating economical products. Further research is necessary to find potential of plant by-products in bars to minimize nutrient wastage and maintain production economy as well. It can be a promising approach for improving nutritional availability to school-children and physically active adolescents to meet nutrition requirements specified by the food authorities.

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