

CHAPTER 2

REVIEW OF LITERATURE

"I think of exercise as the father of the body and nutrition as the mother."

- Mandy Ingber (Maltby, 2014)

A review of literature serves as a comprehensive examination of existing scholarly works relevant to the topic under investigation, providing a foundation for understanding and contextualizing the research at hand (Gurumani, 2019). In the studies related to food science and nutrition, where food product development, innovation and improvement are paramount, such reviews play a crucial role in identifying gaps in knowledge, evaluating methodologies and synthesizing findings to inform new research endeavours. Within this framework, the exploration of the development, optimization and characterization of protein-energy bars using RSM stands as a vital pursuit. With an ever-growing emphasis on health-conscious consumption and the demand for convenient, proteinaceous snacks at an affordable price, the creation of protein-energy bars presents a promising avenue for meeting these needs. This review critically examines the existing body of literature surrounding the formulation and enhancement of protein-based food bars, setting the stage for the exploration of RSM as a tool for optimizing the quality and nutritional profile of protein-energy bars.

The relevant literature pertaining to this topic has been organized into the following categories:

- Section 2.1 Sports Nutrition
- Section 2.2 Importance of Nutrition for athletes
- Section 2.3 Assessment of dietary intake
- Section 2.4 Role of Protein in Athletic Performances
- Section 2.5 Categories of Sports Supplements
- Section 2.6 Sports Bars and its Composition

- Section 2.7 Market Survey of Sports Nutrition Supplements
- Section 2.8 Protein Sources
- Section 2.9 Extruded foods
- Section 2.10 Extruded sports foods
- Section 2.11 Common Ingredients in Food Bars
- Section 2.12 RSM- Response Surface Methodology
- Section 2.13 RSM-CCRD (Central Composite Rotatable Design)
- Section 2.14 Characteristics of Protein Bars
- Section 2.15 Textural Properties
- Section 2.16 Shelf-Life of Protein Bars
- Section 2.17 Packaging and Labeling requirements of Sports Bars
- Section 2.18 Consumption Patterns and Perceptions of Protein Energy Bars Among Athletes and Trainers

2.1 Sports Nutrition

Sports nutrition is a critical aspect of athletic performance, encompassing the science of fuelling the body optimally for exercise, competition and recovery. Proper nutrition can significantly impact an athlete's endurance, strength, speed and overall health, making it a fundamental component of training regimens across various sports disciplines. Through the strategic intake of nutrients, athletes aim to maximize energy levels, promote muscle growth and repair, enhance hydration and support immune function. Additionally, nutritional strategies can aid in weight management and optimize body composition to improve athletic performance (Irandoost K., 2023). Burke et al. (2019) states that in order to maximise performance, preserve health and reduce the chance of sickness and injury, athletes need an adequate amount of energy and nutrients.

The core of sports nutrition is identifying the unique nutritional requirements of physically active people and adjusting dietary plans appropriately. Macronutrients such as carbohydrates, proteins and fats play crucial roles in providing energy, supporting muscle function and aiding in recovery. Proper hydration is also emphasized to maintain performance and prevent dehydration during exercise (Panandiker et al., 2007). Pre-exercise nutrition focuses on consuming balanced meals or snacks rich in carbohydrates to fuel energy stores, while during-exercise nutrition often involves the consumption of carbohydrates to sustain energy levels (Rothschild et al., 2020). According to Winter (2023), post-exercise nutrition is essential for promoting recovery, with a combination of carbohydrates and proteins aiding in glycogen replenishment and muscle repair. Additionally, individualized nutrition plans are crucial, considering factors such as training volume, goals and dietary preferences to optimize performance and overall health (Thomas et al., 2016).

2.2 Importance of Nutrition for athletes

Effective nutrition supports the capacity for intense training, aids in muscle recovery and facilitates metabolic adjustments for endurance exercise. A sufficient energy intake should come from a diverse range of foods rich in carbohydrates, proteins, fats and essential micronutrients.

Rather than functioning as separate entities, nutrition and physiology are deeply intertwined aspects that collectively shape an athlete's ability to perform, endure and excel. Beyond mere sustenance, nutrition in sports embodies a strategic approach to fuelling the body, optimizing performance and facilitating recovery, as articulated by Irandoust (2023).

Assessing the relationship between nutrition and athletic performance reveals that nutrition plays a critical role that, when matched with the right dietary choices, may greatly improve an athlete's performance. On the other hand, inadequate or poor diet can lead to less-than-ideal performance, increased risk of injury and longer recovery times. Vital nutrients, which include carbs, proteins, fats, vitamins and minerals, each have a specific role to play in an athlete's overall health and performance. The idea of energy balance and nutrient timing, which is especially relevant in the context of training and competition, is essential to maximising the use of these nutrients. A deliberate approach to diet not only fuels the body but also acts as a foundation for optimising athletic ability, as highlighted by Irandoust (2023).

Review of Literature

Physical fitness encompasses a physiological condition of overall well-being, enabling individuals to effectively meet the challenges of daily life (referred to as health-related physical fitness) or to excel in athletic endeavours (referred to as performance-related physical fitness), or both. Health-related physical fitness specifically addresses components of physical fitness associated with health status, encompassing cardiovascular fitness, musculoskeletal fitness, body composition and metabolism, as outlined by Warburton et al. (2006). This holistic definition underscores the multidimensional nature of physical fitness, emphasizing its significance not only in enhancing performance but also in promoting optimal health outcomes.

Good genes, appropriate training and conditioning and a balanced diet are all necessary to become an excellent athlete. To perform at your best, you must eat healthfully. An ambitious athlete might suffer just as much from nutritional ignorance as from proper diet. A person who follows a balanced diet and engages in a general exercise plan (e.g., 30–40 minutes per day, most days of the week) can satisfy their nutritional requirements. But in order to achieve their nutritional needs, athletes in moderate- or high-frequency exercise programmes will have to consume more (Clifford and Maloney 2015).

Examining the critical function that nutrition plays in an athlete's diet reveals that nutrition is important for more than just helping the body recover from exercise. Recovery is still important, but there is a growing recognition that nutrition is essential to supporting the changes that happen in muscle and other tissues after every training session (Bergström et al., 1967). Notably, the enhanced capacity for fat burning achieved through training can be partially reversed with a high-carbohydrate diet (Coyle et al., 1997). While this may prove advantageous in scenarios where carbohydrate availability is restricted, its utility in other contexts is debatable, as it could result in an increased energy expenditure during exercise. Moreover, the substrate utilization pattern of muscles is influenced by exercise intensity and evolves over time, modulated by various factors such as protein in diet, previous diet and exercise, fitness level and environmental conditions (Galloway et al., 1997). This review underscores the intricate interplay between nutrition, exercise and physiological adaptations, emphasizing the importance of tailored dietary strategies in optimizing athletic performance.

2.3 Assessment of dietary intake

Dietary assessment plays a crucial role in evaluating the energy and nutrient intake of athletes, aiding in the identification of those requiring nutritional monitoring and support (Thomas et al., 2016). It helps gauge nutritional adequacy, identify deficiencies and tailor dietary recommendations to enhance athletes' training and competitive performance. Common methods for dietary assessment include 24-hour or multiple dietary recalls, food frequency questionnaires, weighted diet records, duplicate portion analysis and chemical analysis. However, several considerations are essential when assessing nutrient intake in athletes. These include adjusting serving sizes to accommodate their higher food consumption, accurately documenting snacking habits, addressing challenges in quantifying beverage consumption during training or matches, scrutinizing supplement intake for credibility and claims and recognizing potential misreporting due to weight control practices such as meal skipping or abnormal eating behaviours (Bhide and Mandalika, 2018).

Leveraging new technologies and techniques for dietary intake assessment offers significant advantages. Utilizing methods like 24-hour dietary recalls featuring images and web-based food frequency questionnaires has proven effective. Tablet and smartphone applications capable of capturing meal images provide convenient tracking options. Employing these innovative approaches enhances compliance and is strongly recommended (Bhide and Mandalika, 2018). It's crucial to carefully validate dietary assessment methods, particularly with emerging technical innovations. These advancements hold promise in aiding portion quantification, reducing data collection burdens and addressing issues like missing foods, particularly among athletes (Capling et al., 2017).

Dietitians stationed in the dining hall during the 2010 Commonwealth Games in Delhi documented the one-day, 24-hour dietary recalls of forty-four athletes who visited the nutrition kiosk. These athletes represented a variety of sports categories, including skill sports, team sports, endurance, power, racquet sports and weight category. The FoodWorks programme was used to analyse dietary consumption. The daily energy consumption ranged from 23,84 to 18,009 kilo Joules (kJ), with a median of 8674 kJ. The percentage of total energy that was attributed to carbohydrates was 50%, with the range being 1.0 to 9.0 g/kg (g/kg) of body weight (median = 3.8). The amounts of fat and protein consumed varied from 10 to 138 g (median = 67 g) and 0.3 to 4.0 g/kg

(median = 1.7), respectively, making up 21% and 24% of the total calorie intake. Athletes reported consuming between 4 and 29 different food items (median = 15) in the previous 24-hour period, with cereals, meats, poultry, fish, eggs and meat alternative items being predominant. However, dairy, fruit and vegetable intake appeared suboptimal, raising concerns about the intake of essential micronutrients such as iron, zinc, calcium and vitamins A and C among many athletes (Burkhart and Pelly, 2016).

Thorat and Thorat (2016) assessed the nutritional status of female athletes in Karad District, Satara. Their findings revealed a higher prevalence of muscle cramps, joint pain, anxiety, lethargy, irritability and tiredness among the athletes. Additionally, the assessment of nutrient intake indicated that protein, vitamin C, beta-carotene and iron consumption fell below the Recommended Dietary Allowance (RDA) set by the National Institute of Nutrition (NIN). Conversely, the consumption of energy, fat, vitamin B1, vitamin B2 and calcium was found to be near the RDA levels.

In house, Departmental Studies on Nutritional Status of Athletes

Chauhan and Inamdar (2015) conducted a study on hockey and tennis players from Baroda, which revealed an unbalanced distribution of calories in their food intake. Despite this finding, no correlation was observed between fitness tests, body composition and nutrient intake. The overall data suggest inadequate dietary intake and physical activity levels, potentially impacting their body composition and overall fitness. The study recommends further investigation into the dietary habits, nutritional status, presence of diseases and fitness profiles of players across various age groups and genders to obtain a more comprehensive understanding of their health and performance.

In research by Chandorkar and Bardoliwala (2015), sportsmen from Baroda who played football and cricket showed inadequate nutrient consumption that fell short of the RDA recommended for non-athletes. The investigation also discovered that the participants consumed an abnormally high amount of fat. In addition, the amount of water that athletes drank during practice sessions was significantly less than what the NIN recommends and most athletes abstained from eating anything during practice sessions. It's interesting to see that more female participants reported taking supplements as recommended by their coaches, mainly for energy and stamina.

Review of Literature

Deota and Chandorkar (2023) performed research on elite cricketers in India, analysing their knowledge, attitude and practices, as well as evaluating the impact of the Nutrition Education Module. This study aims to analyse top cricketers' understanding, attitudes and behaviours about sports nutrition in metropolitan Vadodara, India and to implement an intervention to address identified gaps. The survey discovered that, while the majority of athletes recognised the importance of nutrition in their sport and the participation of nutritionists on their professional teams, only a tiny percentage followed suggested dietary habits for post-match recovery. However, following the intervention, all teams' knowledge ratings improved significantly. Additionally, the study indicated that individuals frequently used supplements, notably sports drinks.

Nutrition education plays a vital role in optimizing athletic performance, especially among high school athletes who often lack adequate knowledge to make informed nutritional decisions. Research indicates a deficiency in nutrition knowledge not only among athletes but also among coaches, trainers and parents at both the high school and collegiate levels. To address this gap, a study was conducted involving 50 hockey athletes (29 boys and 21 girls) aged above 14 years registered with the Sports Authority of Gujarat (SAG) in Vadodara city. Data on nutritional and physiological knowledge were collected and participants were provided with nutrition health education through booklets, brochures and presentations. Post-intervention data collected after 90 days revealed significant improvements in knowledge scores among both boys and girls. Specifically, a notable percentage of participants shifted from fair to good knowledge scores, with highly significant differences observed in girls' knowledge scores across all aspects and in boys' scores for nutritional and total knowledge. None of the players were categorized as having poor or fair knowledge after the intervention. Overall, the study underscores the importance of nutrition education and the role of nutritionists in enhancing sports performance (Chauhan and Joshi, 2021).

According to Chauhan (2017), educational institutions focus on teaching children about the healthcare practices of younger age groups, but there is a lack of emphasis on healthcare for the elderly. Chauhan suggests the development of an education module to address this gap. This module would likely include information on the unique healthcare needs of older individuals, such as preventive measures, management of chronic conditions and promoting overall well-being in later stages of life (<https://epgp.inflibnet.ac.in>, 2017)

Energy Needs of Athletes

In many cases, a well-rounded diet should suffice to maintain energy balance in individuals with heightened energy needs due to physical activity. However, meeting the energy demands of larger athletes or those engaging in high-volume intense training can be challenging (Kreider et al., 2010). Endurance athletes and those in sports where manipulating body composition is common may experience negative energy balance, often attempting rapid and poorly managed weight loss (Loucks et al., 2013). Female athletes, historically more susceptible to eating disorders, may develop the female athlete triad, characterized by disturbed eating patterns, menstrual irregularities and reduced bone mineral density, even without a diagnosed disorder. High-intensity training may suppress appetite, altering hunger cues and gastrointestinal discomfort may deter pre-exercise meals (Kreider et al., 2010).

Travel and training schedules can affect food accessibility and safety, necessitating careful planning. Insufficient energy intake can lead to muscle loss, injury, illness, overtraining syndrome and decreased performance. Athletes should aim for an energy balance tailored to their expenditure, consuming 4-6 nutrient-dense meals daily and considering low-risk supplements like liquid meal replacements and multivitamins (Potgieter, 2013). The availability and consumption of energy bars can offer a convenient solution for athletes striving to maintain energy balance amidst rigorous training schedules and dietary challenges, providing a portable and nutrient-dense option to support their energy needs.

Adequate energy intake serves as the cornerstone of an athlete's nutritional regimen, enabling optimal bodily function, facilitating the consumption of essential macronutrients and micronutrients and aiding in achieving desired body composition goals. According to Thomas et al., (2016). The energy needs of athletes fluctuate based on the periodized training and competition schedule, evolving throughout the year in response to variations in training volume and intensity.

Energy is produced, mostly through the synthesis of ATP (adenosine triphosphate) and calories are obtained from diets that comprise the important macronutrients—fat, protein and carbs. Because the body can only hold so much ATP, it uses three energy systems: the Glycolytic Energy System (used for intense exercises like weightlifting

and sprinting), the Immediate Energy System and the Aerobic Metabolism System (used for endurance sports like swimming and distance running). According to Coyle (2004), there are differences in the distribution of calories and macronutrients across individuals based on factors including age, gender, dietary habits, fitness level, stress, sleep quality and genetic predispositions. These factors also affect the duration, intensity, kind and frequency of workouts.

According to the ISSN guidelines, determining energy needs should be based on both the individual's level of physical activity and their body weight, as outlined in table 2.3.1 (Kreider et al., 2010).

Table 2.3.1 Daily Caloric Requirement for Physical Activity

<i>Exercise Intensity</i>	Daily Caloric Needs (kcal/day)	Caloric Needs (kcal/kg/day)
<i>General Fitness Program (e.g., 30-40 mins/day, 3 times/week)</i>	1,800 - 2,400	25 – 35*
<i>Moderate Levels of Intense Training (e.g., 2-3 hours/day, 5-6 times/week)</i>	2,500 - 8,000	50 - 80
<i>High Volume Intense Training (e.g., 3-6 hours/day, 1-2 workouts, 5-6 days/week)</i>	6,000 - 12,000	50 - 80
<i>Elite Athletes (e.g., Tour de France cyclists)</i>	Up to 12,000	150 - 200

*standard diet, Source: *Kreider et al., (2010)*

When an athlete successfully meets their daily macronutrient needs, it's probable that their total energy intake is adequate. The ACSM guidelines, which are derived from the Dietary Reference Intakes (DRIs), are based on extensively researched equations developed using the gold standard method for assessing free-living energy expenditure: doubly labelled water. These guidelines encompass a range of activity levels, spanning from slight to very active (Rodriguez et al., 2009).

Macronutrient Requirements

Endurance athletes require specific macronutrient intake to support their prolonged aerobic activity and optimize performance. Research suggests, a higher carbohydrate intake is essential for endurance athletes to replenish glycogen stores and sustain energy levels during prolonged exercise. Additionally, adequate protein intake is important to support muscle repair and recovery. Burke et al., (2019) conducted a review that emphasized the importance of carbohydrate periodization techniques. The review highlights the adjustment of carbohydrate intake based on training volume and intensity in order to maximize endurance performance and glycogen store. Moreover, a moderate to high protein intake spread evenly throughout the day is advantageous for improving recovery and adaptation to endurance training, according to Phillips et al., (2012), who also highlights the significance of protein in aiding muscle adaptation and repair in endurance athletes. The amount of fat required by athletes is somewhat more than that of non-athletes. Maintaining general health, balancing calorie intake, getting the best possible intake of fat-soluble vitamins and important fatty acids and restocking intramuscular triacylglycerol reserves all depend on eating enough fat. Depending on the athlete's body composition objectives and training level, different amounts of fat are required (Kreider et al., 2010).

Carbohydrate Requirement in Athlete Diet

Understanding the carbohydrate requirements of athletes is crucial for optimizing performance, recovery and overall health. Numerous studies have investigated this topic, considering factors such as exercise intensity, duration, type, individual differences and timing of carbohydrate consumption. The approach to determining carbohydrate requirements in sports nutrition has evolved from being based on a percentage of total energy intake to a more precise measurement: g per kg (g/kg) of body weight (BW). This shift ensures that athletes receive adequate macronutrients relative to their total energy intake while allowing flexibility for tailoring nutrition plans to specific training regimens (Burke et al., 2013). Athletes, given their higher energy needs and macronutrient requirements compared to sedentary individuals, benefit from expressing these needs in gram per kilo gram body weight, as recommended by the ACSM and American Dietetic Association (ADA). In the opinion of Thomas et al. (2016), this technique offers a useful and individualized way to meet the nutritional demands of athletes ACSM provides general recommendations for athletes as mentioned in the table 2.3.2.

Research demonstrates that glycogen depletion during prolonged exercise can impair performance. Therefore, adequate carbohydrate intake before, during and after exercise is essential for replenishing glycogen stores and maintaining performance (Hawley and Burke, 2010). Consuming carbohydrates before, during and after exercise can optimize glycogen synthesis and improve recovery (Jentjens and Jeukendrup, 2005).

Table 2.3.2 General Recommendations of Carbohydrates for Athletes (ACSM)

Type of Athlete	Carbohydrate Intake (g/kg/d)
General	6 - 10
Heavy Training/Competition	Up to 12
Endurance (prolonged, high-intensity exercise)	Higher intake may be necessary

Source: *Burke et al., (2013)*

Individual factors such as body composition, metabolism, training status and genetics can influence carbohydrate requirements. While some athletes may thrive on lower carbohydrate diets (e.g., ketogenic diets), others may require higher carbohydrate intake to meet energy demands (Burke et al., 2017). Periodizing carbohydrate intake based on training goals and competition schedule is a strategy endorsed by many researchers and sports nutritionists. This involves adjusting carbohydrate intake to match training demands, with higher intakes during intense training periods and tapering before competitions (Stellingwerff and Cox, 2014).

Muscle fatigue and hypoglycaemia often result from decreased muscle glycogen reserves during endurance exercises. Increased glycogen stores in the muscles and liver are necessary for peak performance. Symptoms include poor energy, weariness, sluggishness, delayed recovery, impaired attention, dizziness, irritability and even fainting are frequently brought on by inadequate carbohydrate consumption (Potgieter, 2013). It is strongly recommended to consume carbohydrates when exercising since it promotes the oxidation of exogenous carbohydrates. According to Bhide and Mandalika (2018), this procedure is likely to store liver glycogen for usage at a later time, postponing the onset of weariness and improving the ability to continue exercising. Table 2.3.3 outlines the recommendations for carbohydrate intake tailored specifically for athletes, as endorsed by the Joint Position Stand of the Academy of Nutrition and Dietetics, Dietitians of Canada and the ACSM in 2016.

Table 2.3.3 Recommendations for Carbohydrate Intake During An Event or Exercise

Situation	Carbohydrate Targets	Comments on Type and Timing of Carbohydrate Intake
During brief exercise (<45 min)	Not needed	<ul style="list-style-type: none"> • Various drinks and sports products can offer easily consumable carbohydrates. • Regular carbohydrate consumption during exercise can stimulate parts of the brain and central nervous system, enhancing well-being perception and self-chosen work outputs. • Carbohydrate intake supplements muscle fuel stores during exercise. • Food and drink consumption opportunities vary depending on the rules and nature of each sport. • Both everyday dietary choices and specialized sports products in liquid or solid forms may be beneficial. • Athletes should experiment to find a refuelling plan that aligns with their individual goals, including hydration needs and gut comfort. • Higher carbohydrate intakes correlate with improved performance. • Products containing multiple transportable carbohydrates can facilitate high rates of carbohydrate oxidation during exercise.
During sustained high intensity exercise (45-75 min)	Small amounts, including mouth rinse	
During endurance exercise, including "stop and start" sports (1-2.5 h)	30-60 g/h	
During ultra-endurance exercise (>2.5-3 h)	Up to 90 g/h	

Source: Thomas et al., (2016)

According to Burke et al. (2003), glycogen stores can typically return to normal levels within 24 hours with reduced training and sufficient fuel intake unless there is severe muscle damage. Restoring glycogen is a key objective during post-exercise recovery, especially between bouts of carbohydrate-dependent exercise when optimizing performance in subsequent sessions is crucial. Effective refuelling necessitates both adequate carbohydrate intake and time. Glycogen re-synthesis occurs at a rate of approximately 5 per cent per hour, underscoring the importance of early carbohydrate consumption in the recovery period, ideally at a rate of 1 to 1.2 grams per kg of body weight per hour during the initial 4 to 6 hours.

To maximize the window for effective refuelling, it's recommended to consume carbohydrates early in the recovery phase. This becomes particularly vital when there's less than 8 hours between subsequent training sessions or events (Burke et al., 2013). According to the Joint Position Stand of the Academy of Nutrition and Dietetics, Dietitians of Canada and the American College of Sports Medicine (Thomas et al., 2016), during such times, it is recommended to consume 1-1.2 grams of carbohydrates per kg of body weight per hour for the first four hours, followed by meeting daily fuel requirements.

2.4 Role of Protein in Athletic Performances

In order to enhance overall health, recuperation and athletic performance, sports nutrition is crucial. Since protein is the fundamental building element for muscle growth, repair and maintenance, it is crucial for athletes who wish to reach their full physical potential. Furthermore, the expanding market for sports supplements, particularly those with components related to energy and protein, illustrates how product development is evolving to better meet the specific nutritional needs of athletes.

Scientific literature consistently highlights the critical role of protein in supporting athletic performance. Dietary protein serves as a source of essential amino acids (EAAs) necessary for muscle protein synthesis, facilitating muscle repair and adaptation in response to exercise-induced stress (Phillips, 2017). Additionally, protein intake can aid in preserving lean muscle mass during periods of intense training, preventing muscle breakdown and optimizing recovery (Morton et al., 2018).

When sufficient carbohydrate intake is ensured, the addition of protein does not seem to enhance endurance performance over a period of several days or weeks. However, incorporating protein during or following intense bouts of endurance exercise may mitigate the increase in plasma proteins associated with myofibrillar damage and alleviate sensations of muscle soreness. Despite its potential benefits, research on the impact of protein supplementation specifically on endurance performance remains relatively limited (Jäger et al., 2017).

The ISSN offers an impartial and thorough evaluation concerning protein intake for individuals who are both healthy and engaged in exercise. Table 2.4.1 summarizes the key points of the Society's stance regarding protein intake, timing, sources and supplementation for athletes to optimize muscle protein synthesis and overall performance.

Table 2.4.1 Summary of ISSN Position Statement on Protein and Exercise

Point	Summary
Exercise Stimulus and Protein Ingestion Synergy	Resistance exercise and protein consumption stimulate MPS and have synergistic effects when combined before or after resistance exercise.
Daily Protein Intake Range	For most exercising individuals, a daily protein intake between 1.4–2.0 g/kg body weight/day is sufficient to build and maintain muscle mass, falling within the Acceptable Macronutrient Distribution Ranges (AMDR) set by the Institute of Medicine.
Higher Protein Intake Benefits	Evidence suggests that protein intakes >3.0 g/kg/day may have positive effects on body composition in resistance-trained individuals by promoting fat mass loss.
Optimal Protein Intake Per Serving	Recommendations for maximizing MPS vary with age and recent resistance exercise stimuli. General recommendations include consuming 0.25 g of high-quality protein/kg body weight or an absolute dose of 20–40 g per serving.

Importance of Leucine Content in Protein	Acute protein doses should aim for 700–3000 mg of leucine and/or a higher relative leucine content, along with a balanced array of EAAs.
Distribution of Protein Intake Throughout the Day	Protein doses should ideally be evenly distributed every 3–4 hours across the day to optimize MPS.
Timing of Protein Ingestion	Benefits are derived from pre- or post-workout protein ingestion; however, the anabolic effect of exercise lasts at least 24 hours but diminishes with time post-exercise. Timing may vary based on individual tolerance.
Supplementation versus Whole Foods	While whole foods can meet daily protein requirements, supplementation ensures adequate protein quality and quantity, especially for athletes with high training volumes, along with minimizing caloric intake.
Effectiveness of Rapidly Digested Proteins	Proteins that are rapidly digested and contain high proportions of EAAs and adequate leucine are most effective in stimulating MPS.
Impact of Protein Type and Quality	Different protein types and qualities affect amino acid bioavailability after supplementation.
Focus on Whole Foods for Essential Amino Acids	Athletes should prioritize whole food sources of protein containing all EAAs to stimulate MPS effectively.
Protein for Endurance Athletes	Endurance athletes should ensure adequate carbohydrate intake for performance, with added protein to offset muscle damage and promote recovery.
Pre-Sleep Casein Protein Intake Benefits	Intake of 30–40 g of casein protein before sleep increases overnight muscle protein synthesis and metabolic rate without affecting lipolysis.

Source: Jäger et al., (2017)

Review of Literature

This points above highlights the significance of supplementation in fulfilling protein needs, especially for athletes undergoing rigorous training regimens. While whole foods remain essential for comprehensive nutrition, supplements present a convenient solution to ensure athletes meet their protein requirements without excessive caloric intake, particularly during intense training phases. It also emphasizes the crucial role of whole foods as the primary source of essential amino acids for athletes. While supplements can be a helpful addition, the focus should primarily be on consuming a balanced diet rich in whole foods to support athletic performance and recovery.

The article by DeCesaris (2023) underscores the critical role of protein intake for athletes, aligning with the position statement by the ISSN. In the article also Protein is highlighted as crucial for muscle repair, recovery and importance of maintaining muscle mass, essential for optimal athletic performance. Inadequate protein intake heightens the risk of injury during training, loss of muscle mass and decreased athletic performance. Not only, but it may also lead to secondary effects such as hormonal imbalances and disruptions in thyroid function. The article also emphasizes that athletes typically require higher protein intake compared to the general population, with some studies suggesting up to 2 grams per kg of body weight to support optimal performance. Adequate intake of amino acids, essential for neurotransmitter production, is crucial for mood, sleep and behaviour. Overall, both DeCesaris' article and the ISSN position statement emphasize the pivotal role of high protein intake in the diet of athletes for optimizing performance.

Protein consumption is frequently prioritised by athletes for the purpose of building muscle, although it serves many other essential purposes for both skilled and untrained people. The body constantly produces and breaks down proteins, which are essential for athletes who compete in endurance sports because they aid in repair and provide energy. Protein must be regularly replenished through a balanced diet since the body gets rid of excess. Fink et al. (2011) draw attention to this realisation and stress the complex function that protein plays in promoting both general health and sports performance.

Insufficient protein intake compromises the maintenance and strengthening of vital tissues such as muscles, tendons and organs, affecting overall health and exercise performance. Protein serves as the fundamental building block for various structures in

Review of Literature

the body, including teeth, hair and nails. Without an adequate protein supply, tissues, especially muscles, cannot effectively respond to exercise stimuli, leading to diminished athletic performance and heightened injury risk. Understanding protein's role is crucial for optimizing both general health and exercise outcomes (Jeukendrup and Gleeson, 2019).

Numerous studies have extensively explored the multifaceted role of protein in exercise-related endeavours, highlighting its diverse functions and contributions to athletic performance. This comprehensive analysis of protein's involvement in physical activity spans various domains, encompassing structural support, energy provision, enzymatic activity, hormonal regulation, acid-base balance maintenance, transportation facilitation, fluid and electrolyte equilibrium, immune system fortification and nutrient absorption enhancement (Riddell, et al., 2003; Heaton et al., 2017; Colombani and Mettler, 2011; Porcari et al., 2015; Hopkins et al., 2022; Orlandi 2022; Da Silveira et al., 2021; Gleeson et al., 2004). Table 2.4.2 summarizes findings from these investigations, presenting a cohesive overview of protein's significance in the realm of exercise science.

The quantity of protein required by athletes is still up for discussion, although recent study suggests that they typically need a little bit more than non-athletes. There are athletes that believe they require far more protein than is suggested. Athletes' body weight, sport, training volume and intensity, calorie intake, availability of carbohydrates, age and gender are just a few variables that may affect how much protein they need.

Table 2.4.2 Functions of Protein in Exercise-Related Activities

Function	Description
Structural Constituent	Found in bones, tendons, ligaments, hair, nails, teeth, muscle and organs. Necessary for muscle protein generation during exercise. Inadequate intake may impair performance and increase injury risk.
Energy	Important for energy provision during exercise, primarily through gluconeogenesis. Supports muscle repair and growth post-exercise.
Enzymes	Essential for various functions in sports nutrition, including energy production, protein synthesis, muscle recovery and inflammation reduction.
Hormones	Regulate metabolic reactions; crucial for muscle growth and repair (e.g., testosterone, growth hormone, insulin).
Acid-Base Balance	Maintains pH levels during exercise; proteins like albumin and haemoglobin buffer excess acid, preventing acidosis.
Transport Proteins	Deliver nutrients (e.g., amino acids, iron), oxygen and creatine to muscles; crucial for energy production and performance.
Fluid and Electrolyte Balance	Maintains electrolyte balance, critical for hydration and performance; proteins help regulate ion movement across cell membranes.
Immunity	Proteins (e.g., antibodies, cytokines) essential for immune function; excessive exercise can suppress immunity, necessitating adequate rest and recovery.
Nutrient Absorption	Enzymes and transport proteins responsible for breaking down and delivering nutrients to cells; crucial for overall health and performance.

Source: (Riddell, et al., 2003; Heaton et al., 2017; Colombani and Mettler, 2011; Porcati et al., 2015; Hopkins et al., 2022; Orlandi 2022; Da Silveira et al., 2021; Gleeson et al., 2004).

Accurately assessing an athlete's protein requirements requires taking these factors into account. Table 2.4.3 describes such factors that influencing protein utilization in athletes based on suggestion made in research (Taylor and Lemuel, 2012; National Research Council, 1989; Riddell et al., 2003; Lemon, 2000; Tipton and Wolfe, 2004; Tipton, 2001; Tarnopolsky, 2003; Bhide and Mandalika, 2018).

Table 2.4.3 Factors Influencing Protein Utilization in Athletes

Factor	Description
Calorie Intake	Inadequate calorie intake may increase the need for dietary protein, as it may be diverted for energy instead of its primary functions like tissue repair. Increased energy expenditure through exercise can have a similar effect. Strength athletes may require higher protein intake to maintain muscle synthesis.
Carbohydrate Availability	Carbohydrates are the main fuel for moderate to intense exercise. Depletion of glycogen stores during intense exercise may increase reliance on protein for energy. Consuming carbs during exercise can spare protein.
Intensity and Duration	Protein utilization varies based on exercise intensity and duration. During aerobic exercise, protein supplements energy, while high-intensity, long-duration exercise may deplete glycogen stores, increasing amino acid use for energy. After resistance exercise, amino acids support muscle synthesis.
Training Status	Initial training stages may increase protein needs due to negative nitrogen balance, which normalizes with adaptation. Resistance training onset may require higher protein for synthesis. Over time, protein needs decrease due to efficiency.
Protein Quality	Essential amino acids, obtained from diet, support protein functions. Athletes need high-quality protein sources for muscle synthesis. Vegetarian athletes should select protein-rich foods to prevent deficiency.

Body Weight	Athletes adjusting weight may require increased protein for recovery, energy and nitrogen balance maintenance. Adequate calorie intake is crucial to meet protein needs for regulatory and structural functions.
Gender	Gender differences in muscle metabolism may exist due to muscle mass variations and hormonal influences. Testosterone affects muscle synthesis, but differences in rates between genders are not significant. Substrate oxidation varies between males and females.
Age	Young athletes need protein for growth and training demands. Aging leads to sarcopenia, necessitating protein to maintain muscle mass. Older adults engaging in resistance training can observe muscle hypertrophy and may require protein intake similar to young athletes.

Source: (Taylor and Lemule, 2012; National Research Council, 1989; Riddell et al., 2003; Lemon, 2000; Tipton and Wolfe, 2004; Tipton, 2001; Tarnopolsky, 2003; Geetanjali and Mandalika, 2018).

Protein serves as the fundamental building block for tissues, crucial for repair and growth, especially after intense physical activity. Early research by Tarnopolsky, (2003), Phillips (2004) and Lemon (2000) highlighted that athletes require significantly higher protein intake compared to sedentary individuals. Phillips, (2004) report recommended a daily protein intake of 1.2 to 1.33 g per kg of body weight for athletes. However, factors such as exercise volume, age and body composition complicate universal recommendations. Recent studies suggest that optimal protein doses, around 20-40 grams per meal, effectively stimulate muscle protein synthesis (MPS) and promote muscle growth. The timing and distribution of protein intake also play crucial roles in maximizing MPS rates and overall athletic performance (Jäger et al., 2017). Snacking between meals with protein, carbohydrates and employing a protein pacing strategy of 4-6 meals per day have shown positive effects on muscle mass, body composition and physical performance. This comprehensive approach to protein intake offers benefits for athletes aiming to enhance muscle mass, improve body composition and optimize performance while maintaining overall health. Based on the review by ISSN (Jäger et al., 2017), table 2.4.4 summarizes the recommendation for protein intake in athletes.

Table 2.4.4 Recommendations for Protein Intake in Athletes

Recommendation	Description
Current RDA for protein	0.8 g/kg/day, but not suitable for athletes as it underestimates their needs.
Previous recommendations	Suggested 1.2–1.3 g/kg/day, based on nitrogen balance technique, which underestimates needs.
Factors influencing needs	Include volume of exercise, age, body composition, total energy intake and training status.
Minimum recommended intake	1.4 to 2.0 g/kg/day, with higher amounts possibly needed for those restricting energy intake while maintaining fat-free mass.
Protein intake per serving for athletes	General recommendations: 0.25 g of high-quality protein per kg of body weight or an absolute dose of 20–40 g.
Higher doses for specific groups	Elderly individuals may need higher doses (~40 g) to maximize MPS responses. Even higher amounts (~70 g) might be necessary to promote attenuation of muscle protein breakdown.
Feeding episode timing	Spacing feeding episodes approximately three hours apart consistently promotes sustained, increased levels of MPS and performance benefits.

Source: Jäger et al., (2017)

The Sports Authority of India (SAI), International Life Sciences Institute (ILSI) and National Institute of Nutrition (NIN) published the Nutrition and Hydration Guidelines for Excellence in Sports Performance guidebook, which includes recommendations for protein consumption (Panandiker et al., 2007). According to the standards, table 2.4.5 outlines the recommended protein for Indian athletes.

The International Olympic Committee (IOC) provides guidelines for athletes' protein and carbohydrate consumption. The IOC had released rules on protein intake for both general athletes and strength-training athletes (Table 2.4.6). Furthermore, according to the IOC, body composition may be optimised by modifying protein and carbohydrate consumption in conjunction with a hypo-energetic diet and specialised exercise regimen.

Table 2.4.5 Recommended Protein for Indian athletes (SAI).

Protein Recommendation	Amount (g/kg bd wt./day)
Recommended Daily Allowance (RDA)	0.8
Endurance Athletes and Bodybuilders	1.0 - 1.5
Active individuals within caloric range	10-15 per cent of total calories
Protein as fuel during exercise	
- Rest and low/moderate exercise	2 per cent - 5 per cent of energy needs
- Endurance exercise	10 per cent - 15 per cent of energy needs
Protein recommendation for athletes	
- General	1.2
- Certain events	Up to 2.0

Source: Panandiker et al., (2007)

Table 2.4.6 International Olympic Committee (IOC) Protein and Carbohydrate Intake Guidelines for Athletes.

Protein Recommendation	Amount (g/kg bd wt./day)
General Athletes	1.3 - 1.8
Strength-training Athletes	1.6 - 1.7
IOC Recommendations	
- Protein Intake	1.8 - 2.7
- Carbohydrate Intake	3 - 4

Source: Slater and Phillips, (2013); Phillips and Loon, (2011)

Studies suggest a shift from traditional protein intake guidelines, which focused solely on total daily intake (grams per kg of body weight). Instead, research indicates that optimizing muscle adaptation to training involves consuming protein targets of 0.3 grams per kg of body weight after key exercise sessions and spreading protein intake evenly every 3 to 5 hours across multiple meals (Moore et al., 2009; Phillips, 2014). Additionally, milk-based protein consumption following resistance exercise has been shown to effectively enhance muscle strength and induce favorable changes in body composition, as demonstrated in several chronic training studies conducted by Hartman et al. (2007), Josse et al. (2011) and Josse et al. (2009).

Recommendations Before, During and After Exercise

Comprehensive recommendations for protein consumption prior to, during and following exercise are provided by the International Society of Sports Nutrition (ISSN) in order to maximise athletic performance and speed up recovery. A pre-event meal, usually three to four hours before training or competition, should contain 0.15-0.25 g/kg body weight (BW) of protein and 1-2 g/kg BW of carbs. A 3:1 or 4:1 protein to carbohydrate ratio has been demonstrated to improve muscle glycogen reserves, reduce muscle damage and improve endurance performance during exercise. The best gains in strength and muscle growth are seen with rapid post-exercise protein ingestion, according to long-term training research. The ISSN recommends supplementing with 0.2–0.5 g/kg BW of protein for recovery or adding protein to carbs at a ratio of 3–4:1. Muscle protein synthesis is stimulated when 6–20 g of essential amino acids (EAAs) are combined with at least 30–40 g of high-glycemic index carbohydrates after exercise. To further improve muscle adaptation and recovery, a tiny quantity of creatine (0.1 g/kg BW) should be added to the protein and carbohydrate mixture (Kerksick et al., 2008; Josse et al., 2009).

Requirement of Fat in Athlete Diet

Athletes require slightly higher fat intake compared to non-athletes to support optimal health, energy balance, essential fatty acid intake and fat-soluble vitamin absorption. Adequate fat consumption is also crucial for replenishing intramuscular triacylglycerol stores. The specific amount of fat needed varies depending on the athlete's training status and goals (Potgieter, 2013).

Different organizations provide varying recommendations for fat intake among athletes. According to Kreider et al. (2010), the ISSN suggests a moderate fat intake of 30 per cent of total energy for athletes, with the possibility of increasing to 50 per cent of total energy for high-volume training, such as elite competitor training akin to the Ironman, which involves approximately 40 hours per week. Conversely, Rodriguez et al. (2009), as per ACSM guidelines, recommend a fat intake ranging from 20 per cent to 35 per cent of total energy intake, with a minimum threshold of 20 per cent. To facilitate body fat reduction or weight loss, Kreider et al. (2010) suggest a fat intake of 0.5-1.0 g/kg bw/day. Additionally, emphasis should be placed on incorporating dietary sources rich in unsaturated fats and essential fatty acids. Sundgot-Borgen and Garthe (2011), following IOC recommendations, propose a daily fat intake ranging from 15 per cent to 20 per cent of total energy.

Fat-loading strategies, including ketogenic diets, are sometimes adopted by endurance athletes before competitions. However, such practices lack scientific evidence supporting performance enhancement (Schek et al., 2019). While high-fat diets may offer certain benefits in specific scenarios, they generally diminish metabolic flexibility by reducing carbohydrate availability and the capacity to utilize carbohydrates effectively during exercise (Burke et al., 2015). Attempts to increase fatty acid availability through acute or chronic fat-loading strategies, with or without subsequent glycogen replenishment, have not shown improvements in endurance performance, despite enhancing fatty acid oxidation. In fact, fat loading may even impair performance in intermediate or final sprints, making low-carb, high-fat diets unsuitable. The use of dietary supplements aimed at improving fatty acid availability/oxidation is generally discouraged (Schek et al., 2019).

2.5 Categories of sports supplements

Maughan et al. (2018) provided a comprehensive definition of dietary supplements, also called nutrition ergogenic aids, characterizing them as substances deliberately ingested alongside the habitual diet to attain specific health or performance benefits. This definition encapsulates a wide range of products, including foods, food components, nutrients and non-food compounds, all consumed with the intention of augmenting overall well-being or enhancing athletic performance.

Table 2.5.1 provides a concise overview of the different forms in which dietary supplements are available, as described by Maughan et al. (2018). Such supplements vary widely in composition and form, ranging from vitamins, minerals and herbal extracts to protein powders, amino acids and ergogenic aids. The use of dietary supplements is prevalent among athletes and fitness enthusiasts seeking to optimize their nutritional intake and achieve their performance goals. However, it is crucial to approach supplement usage with caution, considering potential risks, regulatory oversight and individual variability in response (Peeling et al., 2019).

Table 2.5.1 Forms of Dietary Supplements

Form of Dietary Supplements	Description
Functional Foods	Foods enriched with additional nutrients or components beyond their typical nutrient composition. Examples include mineral-fortified, vitamin-fortified and nutrient-enriched foods.
Formulated Foods and Sports Foods	Products designed to provide energy and nutrients in a more convenient form than regular foods. They can serve as general nutrition support (e.g., liquid meal replacements) or target specific needs around exercise (e.g., sports drinks, gels, bars).
Single Nutrients and Components	Isolated or concentrated forms of individual nutrients or other components found in foods or herbal products.
Multi-Ingredient Products	Products containing various combinations of the aforementioned forms, targeting similar outcomes.

Source: Maughan et al., (2018)

In accordance with the IOC Expert Group Statement on Dietary Supplements in Athletes (2018), dietary supplements comprise a wide range of products, from vitamins, minerals, proteins and amino acids to herbals, botanicals and specialty formulations meant to support and improve performance. These supplements are essential parts of athletes' nutrition plans since they support their nutritional needs at different stages of training, competition and recuperation. Moreover, energy bars, gels, beverages and supplements are examples of sports foods that play a critical role in providing athletes with the nutrition they need in a variety of situations, such as during training, competition and the recovery phase following an activity session (Maughan et al., 2018).

Figure 2.5.1 provides a summary of the roles and ingredients commonly found in sports foods, including isotonic and high-energy sports drinks, electrolyte supplements, sports gels, protein supplements, sports bars, confectionery and liquid meal supplements. These products serve various physiological goals such as hydration, fuelling, anabolism and osmolality regulation, achieved through active ingredients like water, carbohydrates, proteins and electrolytes. Sports foods offer advantages such as tailored ingredient compositions for exercise needs, optimized serving sizes, convenience and digestibility. However, concerns exist regarding their costliness compared to everyday foods, potential limitations in meeting overall nutrient requirements and the risk of reduced dietary variety with overreliance on sports foods as energy sources. It's noted that many sports nutrition goals can be met with more affordable everyday food alternatives.

Upon establishing a comprehensive training regimen, effective recovery strategies and a well-balanced nutrition plan, athletes may then consider the utilization of performance supplements to potentially enhance marginal gains, as suggested by the IOC Expert Group Statement on Dietary Supplements in Athletes (2018). However, the literature highlights a prevalent trend where athletes' supplementation decisions are predominantly influenced by sources such as family, friends, teammates, coaches, internet resources and retailers, rather than guidance from qualified sports dietitians. This discrepancy underscores the importance of raising awareness regarding the significance of seeking expert advice when making supplementation choices, as emphasized in studies such as Braun et al. (2009).

When analysing the utilization of dietary supplements based on factors such as sport type, elite versus non-elite athletic status and the type of supplements, a considerable variability in prevalence of use was observed across studies, as indicated by Knapik et al. (2016). Elite athletes exhibited notably higher rates of dietary supplement usage compared to their non-elite counterparts. While the prevalence of dietary supplement use appeared to be similar between men and women for most supplements, variations were noted in the usage of specific supplements such as iron, creatine, protein and vitamin E.

Product	Active ingredient	Water	Carbohydrates	Protein	Electrolytes
	Physiological goal	Hydration	Fueling	Anabolism	Osmolality
Isotonic sports drink		✓✓	✓		✓
High-energy sports drink		✓	✓✓		✓
Electrolyte supplement (drink form)		✓			✓✓
Sports gel			✓✓		
Protein supplement (drink form)		✓	✓	✓✓	✓
Sports bars			✓	✓	✓
Sports confectionary			✓✓		
Liquid meal supplements		✓	✓✓	✓	✓
Advantages of sports foods		<ul style="list-style-type: none"> • Sports foods can contain only those ingredients that are actually needed during exercise. Foods in the general food supply, particularly whole foods, will usually contain other nutrients, such as fat and fibers, which are not needed during a race, and may cause gastrointestinal discomfort. • Sports foods may be manufactured to optimize serving size, convenience, digestibility, storage, and transport. 			
Concerns about sports foods		<ul style="list-style-type: none"> • Sports foods are more expensive than “everyday foods” and may drain an unnecessarily large share of the athlete’s budget. It should be noted that many sports nutrition goals can easily be met with the use of everyday foods. A typical example is the protein-rich recovery drinks that can be adequately replaced by the much cheaper dairy products (e.g., skim milk or yogurt). • An overreliance on sports foods as energy sources may lead to poor nutrient intake and limited dietary variety. 			

✓ Can contribute to this goal. ✓✓ Is an important contributor to this goal.

IJSNEM Vol. 29, No. 2, 2019

Source: Peeling et al., 2019

Figure 2.5.1 Summary of the Roles and Ingredients in Sports Foods

Table 2.5.2 summarizes the categories of muscle-building and performance enhancement supplements, along with the evidence supporting their efficacy and safety, as outlined in the literature provided.

Table 2.5.2 Summary of Muscle Building and Performance Enhancement Supplements: Evidence for Efficacy and Safety

Supplements	Evidence for Efficacy and Safety
Muscle Building	
Strong Evidence:	-Hydroxy β -methylbutyrate (HMB) - Creatine monohydrate - EAA - Protein
Limited or Mixed Evidence:	- Adenosine 5'-triphosphate - Branched-chain amino acids (BCAA) - Phosphatidic acid
Little to No Evidence:	- Agmatine sulfate - α -ketoglutarate (α -KG) - Arginine - Boron - Chromium - Conjugated linoleic acids (CLA) - D-aspartic acid - Ecdysterones - Fenugreek extract - Gamma oryzanol (ferulic acid) - Glutamine - Growth hormone releasing peptides (GHRP) and secretagogues - Isoflavones - Ornithine- α -ketoglutarate (OKG) - Prohormones and anabolic steroids - Sulfo-polysaccharides (myostatin inhibitors) - Tribulus terrestris - Vanadyl sulfate (vanadium) - Zinc/magnesium aspartate (ZMA)
Performance Enhancement	
Strong Evidence:	- β -alanine - Caffeine - Carbohydrate - Creatine monohydrate - Sodium bicarbonate (baking soda) - Sodium phosphate - Water and Sports drinks
Limited or Mixed Evidence:	- L-alanyl-L-glutamine - Arachidonic acid - BCAA - Citrulline - EAA - Glycerol - β -hydroxy β -methylbutyrate (HMB) - Nitrates - Post-exercise carbohydrate and protein - Quercetin - Taurine
Little to No Evidence:	- Arginine - Carnitine - Glutamine - Inosine - Medium chain triglycerides - Ribose

Source: Kerksick et al., (2017)

The market for sports supplements is saturated with a plethora of protein supplements, which utilize a range of animal and vegetarian protein sources. These supplements often come with a hefty price tag, largely attributed to extensive marketing efforts and the intricate processing methods involved. As highlighted by the Australian Institute of Sport (AIS) in 2014, the proliferation of protein supplements has led to a competitive market where various brands vie for consumer attention. Despite their costs, protein supplements remain popular among athletes and fitness enthusiasts due to their perceived effectiveness in promoting lean muscle mass gain, especially when combined with resistance training. This assertion is supported by Hector and Phillips (2018), who underscore the synergistic relationship between protein supplementation and resistance exercise in facilitating muscle growth and development.

Cermak et al. (2012) did a meta-analysis utilising data from 22 published trials with a total of 680 individuals to evaluate the impact of protein supplementation on changes in fat-free mass and strength. The results indicated that both younger and older individual's fat-free mass and lower body strength were positively impacted by protein supplementation. Similar to the previous meta-analysis, one more study also found that protein intake can improve the accumulation of fat-free mass in participants, with the best results being shown at around 1.62 g of protein per kg of body weight per day (based on data from 49 studies and 1863 individuals) (Morton et al., 2018). Nevertheless, beyond this limit did not result in additional enhancements in mass increases without fat. Even while this area still needs further research, the data that is already available highlights the increased protein needs during intense training. Increased protein consumption during exercise increases the likelihood that fat-free mass will alter significantly in athletes. Individuals who exercise should strive for 1.4 to 2.0 grams of protein per kg of body weight per day, according to ISSN, which is backed by studies by Jager et al. (2017), Morton et al. (2018) and Stokes et al. (2018).

For athletes, the quality of their dietary protein is critical. High biological value (BV) proteins should be consumed to provide sufficient intake of EAA. Compared to plant-based proteins, which might not include all or some EAA, animal-based proteins, especially those found in dairy products are higher in EAA and have better anabolic qualities. Hydrolyzed whey isolate, micellar casein and soy isolate were the three protein sources that were found to significantly increase muscle protein synthesis both at rest and after resistance exercise in a study examining the effects of different protein sources on muscle protein synthesis (Hartman et al., 2007). Enhanced endurance performance and upper-body power have been associated with increases in plasma leucine and total BCAA concentrations (Kårlund et al., 2019).

The IOC has recommended a protein content per serving ranging from 20 to 50 g for sports supplements (Maughan et al., 2018). However, guidelines regarding calorie content, sugar or sweetener content and protein quality are lacking. Despite their potential benefits, supplement use carries inherent risks. Poor manufacturing practices may lead to microbiological contamination or the presence of hazardous foreign objects in the supplement. Additionally, expensive ingredients may be under-dosed or absent altogether from the product, raising concerns about efficacy and safety. Instances of athletes failing doping tests due to undisclosed ingredients in supplements highlight the importance of cautious product selection (Maughan, 2013).

2.6 Sports Bars and its Composition

Historical evidence suggests that food (energy) bars have been present since the middle ages (1095 – 1492), with crusaders carrying an energy bar called pan forte—made of flour, honey, shortening, nuts and dried fruit—for sustenance during long marches. In modern times, these bars evolved from their original identity as space food for astronauts, known as "Space Food Sticks," introduced by the Pillsbury Company in the late 1960s. Initially designed as non-frozen balanced energy snacks, these bars contained nutritionally balanced amounts of carbohydrate, fat and protein. Later, Canadian marathoner Brian Maxwell commercially released "Power Bars" in 1986, targeting athletes with high energy needs (Saxena, 2018). Over time, energy bar manufacturers have adapted their marketing strategies to cater to varying consumer needs. Presently, nutrition bars are widely consumed by everyday individuals and are positioned as healthful foods suitable for consumption as meal parts, between meals, or as meal replacements.

The review outlines the distinct characteristics of various types of nutrition bars, encompassing high protein bars, protein bars, high energy bars and balanced carbohydrate/protein/fat bars. Traditionally utilized as supplements in high protein weight loss programs or as protein supplements by bodybuilders, high protein bars typically contain slightly less protein compared to traditional high protein bars. Geared towards offering immediate energy or sustained endurance, high energy bars present a balanced nutrition profile with 20 to 40 g of protein, 10 to 20 g of carbohydrate, 5 to 10 grams of fat and 130 to 230 calories per 50 g serving size. Conversely, protein bars provide 10 to 15 g of protein, 15 to 25 g of carbohydrate, 5 to 15 g of fat and 180 to

240 calories per 50 g serving size. Balanced carbohydrate/protein/fat bars are designed to deliver balanced nutrition, offering 2 to 9 g of protein, 30 to 40 g of carbohydrate, 5 to 15 g of fat and 160 to 230 calories per 50 g serving size. Lastly, nutrition bars typically include 5 to 10 g of protein, 20 to 30 g of carbohydrate, 5 to 20 g of fat and 200 to 275 calories per 50 g serving size (Ayatti, 2021).

The sports nutrition market has witnessed a surge in product diversification and innovation, with a particular focus on developing supplements tailored to athletes' specific needs. Protein-energy sports supplements, blending protein with carbohydrates and other energy-enhancing ingredients, have gained popularity due to their ability to provide both immediate and sustained fuel for athletic performance (Witard et al., 2019). Moreover, advancements in formulation technologies have enabled the creation of products with improved taste, texture and bioavailability, enhancing their palatability and efficacy for athletes (Martens and Westerterp-Plantenga et al., 2012).

Understanding consumer trends and preferences is crucial in guiding product development efforts within the sports nutrition industry. Athletes increasingly prioritize products that are not only effective but also convenient, portable and backed by scientific evidence. Furthermore, there is growing demand for products that cater to specific dietary preferences and restrictions, such as plant-based or allergen-free formulations, reflecting the evolving needs of diverse athlete populations (Arenas et al., 2020).

A foundation of cereals like oats, rice or maize, or proteins like soy, dairy or whey which are frequently fortified with vitamins, minerals and other nutrient-rich ingredients is used to create bars (Gonzalez and Draganchuk, 2003; Aramouni and Abu-Ghoush, 2011). Snack bars are popular because they may be healthier than other food options. Preferring less processed and more natural options in food and drink has been fuelled by recent trends in health and wellbeing. Additionally, nutrient-dense snacks are a great way for those with busy lifestyles and those who are experiencing global food scarcity to get energy and micronutrients (Aramouni and Abu-Ghoush, 2011).

There has been a significant increase in the market for high-protein snack bars, especially from those who are athletes and following diets or meal replacement plans. With their high protein content (which ranges from 15 per cent to 35 per cent by weight)

and other healthier ingredients, these bars provide a nutritious substitute for traditional snacks (Hogan et al., 2012). Cereal bars are incredibly versatile; they combine processed cereals with different ingredients to cater to different target markets (Bower and Whitten, 2000). For example, wheat and/or soy bars are created as nutrient-dense solutions for people who are always on the go (Aramouni and Abu-Ghoush, 2011). Food bars consist of ingredient combinations presented in a solid, low-moisture format, offering nutritional benefits rather than serving as confectionery treats. These bars are crafted to encompass a diverse array of nutrients and are strategically marketed to target different consumer preferences and needs. Different formulations, processing and functionality for snack bars, as detailed in various research studies, are presented in table 2.6.1.

Table 2.6.1 Snack Bar Formulations

Snack Bar Type	Ingredients and Process
Fruit-based Snack Bar (Sun-Waterhouse, 2010)	Base: rice crisps, glucose syrup, honey, vegetable oil, quick-cook rolled oats (or natural apple dietary fibre or inulin), glycerol, whey protein concentrate, maltodextrin, pectin; Filling: pectin, sugar, citric acid, glucose syrup, honey, vegetable shortening, glycerol and apple purée. Process: Base: mix dry and wet ingredients, mold and bake at 130°C/15 min; Filling: heat ingredients with stirring to 84-86 per cent soluble solids content; Assembly: place filling between base parts.
Wheat- or Soy-based Bar (Aramouni, 2011)	Ingredients: water, corn syrup, glycerine, brown sugar, Arabic gum, emulsifier, puffed wheat, wheat germ, commercial coatings, shortening, soy nuggets, soy protein, soy fibre, vanilla extract. Process: mix and blend ingredients in different proportions to obtain various bars; heat puffed wheat, wheat germ, soy nuggets, soy protein, soy fibre; mold and cool bars.
Cereal Snack Bar (Da Silva, 2014)	Ingredients: corn starch biscuit, skimmed milk powder, rice flakes, oat flakes, corn syrup. Process: mix dry ingredients, add syrup, seal, cool, cut and pack.

<p>Fruit and Vegetable-based Snack Bar (Ferreira, 2015)</p>	<p>Ingredients: Sweet - fruit and vegetable flour, rice flour, oat flakes, linseeds, sucrose syrup, brown sugar, cocoa powder. Salty - fruit and vegetable flour, rice flour, oat flakes, linseeds, egg white, olive oil, condiments. Process: Sweet - heat sucrose syrup, mix with dry ingredients. Salty - mix ingredients, mold, bake, cool, coat, seal.</p>
<p>Cereal Snack Bar (Silva, 2016)</p>	<p>Ingredients: crushed corn starch biscuit, oat, skimmed milk powder, rice flakes, corn syrup. Process: mix dry ingredients, add syrup, mix, coat, rest, mold.</p>
<p>Vegetable-based Snack Bar (Ramírez-Jiménez, 2018)</p>	<p>Ingredients: bean flour, oat flakes powder, water, soy lecithin. Process: mix ingredients, coat, cut, bake, cool, pack.</p>
<p>High-Protein Snack Bar (Hogan, 2012)</p>	<p>Ingredients: milk protein, high fructose corn syrup, glycerol. Process: mix ingredients, mold.</p>

Source: Constantin and Istrati, (2018)

In a report on snack food consumption in the USA, snack, cereal and nutrition bars are typically categorized into three main groups: health and wellness snacks, organic snack bars and energy and nutrition bars. Consumption patterns of snack bars are often shaped by factors such as age, gender and consumer knowledge of nutrition. Additionally, according to market indicators from the International Markets Bureau, consumption of snack bars is influenced by various factors including fulfilling cravings for sweetness, time-saving convenience, serving as an energy boost, aiding in weight loss efforts and providing essential nutrients such as protein, fiber and vitamins (Constantin and Istrati, 2018).

In today's fast-paced lifestyle, traditional meals are often replaced by quick snacks due to long working hours. This shift in eating habits highlights the ongoing demand for convenient, nutritionally rich food options (Mestdag, 2005). Concurrently, the modern lifestyle increasingly integrates physical activities and sports to support overall health. However, these activities necessitate protection against mechanical stress and the

heightened production of free radicals, which can induce oxidative damage to essential molecules (Dantas et al., 2014). Additionally, as more people engage in physical activities and sports to support their health, there's a need for products that provide quick replenishment of energy and nutrients post-exercise. High-protein bars, originally developed for athletes to build muscle mass, are increasingly popular for their ability to offer immediate nutrition without the time-consuming meal preparation (Sloan, 2022).

Growing consumer awareness about the role nutrition in sports performance and a trend towards convenience-oriented lifestyles have propelled the sports snack bar industry's recent notable expansion. Sports food bars offer athletes with a quick and portable way to satisfy their dietary requirements prior to, during and following exercise. They are frequently made with a balance of carbohydrates, protein and fats (Burke and Cox, 1995). The importance of protein-rich bars in supporting muscle protein synthesis and assisting in muscle development and repair is highlighted in research by Jovanov et al. (2021), especially when ingested after exercise.

2.7 Market Survey of Sports Nutrition Supplements

In 2022, the global Protein Bar market was valued at USD 1250.9 million, with a projected Compound Annual Growth Rate (CAGR) of 6.5% expected for its future expansion, reaching USD 1824.89 million over the forecast period. This market includes various types such as Sports Nutritional Bar and Meal Replacement Bar, catering to diverse consumer needs. Key factors driving market growth include global diversity, ongoing product innovation and segmentation strategies. Long-term growth projections, market dynamics, regulatory changes and competitive landscapes also influence strategic decisions. Fluctuations in consumer demand for different protein bar types further shape market trends and growth prospects (Size, 2023: <https://www.researchandmarkets.com/tag/energy-bar>).

The India Energy Bar Market, valued at USD 3.91 million in 2024, is projected to reach USD 8.83 million by 2029, with a CAGR of 17.69% during the forecast period. Amid the Covid-19 pandemic, Indian energy and protein bar companies expanded into online channels and began exporting globally. Fit Sport Nutrition Foods, based in Hyderabad, successfully entered the competitive US market through Amazon listings. The pandemic-induced shift towards healthier lifestyles increased demand for energy bars

among gym-goers and health-conscious consumers. Convenience, health consciousness and the trend towards smaller, frequent meals boosted sales, alongside rising sports participation and gym attendance. However, perceived high prices compared to regular snacks in India present an opportunity for local players like Patanjali to offer more affordable options. Key players such as Unibic, Yoga Bar, General Mills, HealthKart and Eat Anytime dominate the market. To enhance product visibility, manufacturers are expanding distribution channels and using innovative marketing strategies. Some companies target specific genders by launching bars with tailored ingredients, providing a personalized experience for consumers (Size, 2023).

In February 2022, Yoga Bar expanded its product range by introducing new mixes named 'Yo Chos' and 'Yo Fills', targeting children's nutrition, thus diversifying their offerings to reach a wider consumer base. Similarly, in January 2021, Clif Bar and Company launched Clif Bar Thins, a thin and crispy energy snack bar available in three flavors with each bar containing 100 calories, 5 g of sugar and featuring plant-based organic ingredients like rolled oats, aiming to provide consumers with a healthier snacking option (Size, 2023). The key global players in the protein bar market, including General Mills, Simply Good Foods, Caveman Foods LLC, Kellogg Company, Nestlé S.A., Clif Bar and Company and others, represent a diverse range of companies contributing to the industry's growth and innovation with their unique products and strategies. <https://www.polarismarketresearch.com/industry-analysis/protein-bar-market>.

Gill and Singh's study conducted in October 2019 sheds light on the dynamic landscape of the Indian energy bar market, revealing a robust presence of both domestic and international brands. Despite the entry of renowned global players such as Clif Bar and Co and Post Foods LLC into the Indian market, it's apparent that domestic firms hold significant sway, dominating the sector. This observation underscores the importance of understanding and catering to local preferences and market dynamics. The emergence of homegrown brands like Yoga bar™, Eat Anytime™ and RiteBite™ signals a shift towards products tailored to Indian tastes and lifestyles, reflecting the growing demand for convenient, nutritionally dense snacks in the country.

The extensive list of Indian and US-based energy bar brands presented in the study highlights the diversity and competitiveness of the market. With a plethora of options available to consumers, ranging from established international names to emerging

Indian players, competition is fierce, driving innovation and product differentiation. Gill and Singh's (2020) findings underscore the significance of offering a wide range of choices to meet the diverse needs and preferences of consumers. Moreover, the study reveals the increasing popularity of energy bars as convenient, on-the-go snacks that provide sustained energy, appealing to health-conscious individuals and athletes alike. This trend not only signifies the growing acceptance of energy bars as a mainstream snack option but also presents ample opportunities for brands to capitalize on the burgeoning market demand.

2.8 Protein Sources

Companies capitalize on this trend by developing products designed to enhance athletic performance or aid in post-exercise recovery. Sports drinks and protein bars are prime examples of such products, offering athletes hydration and additional energy. These products often contain added nutrients to optimize physical performance (Schneider and Benjamin, 2011). Protein, a key nutrient found in many of these products, plays a vital role in muscle growth and supports the body's immune system (Van der Zanden et al., 2014). Additionally, protein can serve as an energy source during intense physical training and facilitate muscle recovery afterward (Hoffman and Maresh, 2011). To promote muscle growth, the net protein balance growth minus breakdown should ideally be positive (Van der Zanden et al., 2014).

Protein is found in various dietary sources, including both animal and plant-based foods, as well as sport supplements. Assessing the effectiveness of protein involves evaluating its quality and digestibility. Quality refers to the availability of essential amino acids, while digestibility indicates how efficiently the body can utilize the protein. Animal protein sources are generally considered complete, containing all essential amino acids. In contrast, vegetable protein sources are often incomplete, lacking one or more essential amino acids. Vegetarians must consume a diverse array of vegetables, fruits, grains and legumes to ensure they obtain all EAAs. Despite this, it's possible for individuals to meet their protein needs without consuming meat or dairy products. Protein digestibility ratings assess how efficiently the body can utilize dietary protein sources. Generally, animal proteins score higher in terms of biological value, net protein utilization, Protein Digestibility-Corrected Amino Acid Score (PDCAAS) and protein efficiency ratio compared to vegetable proteins (Hoffman and Falvo, 2004).

Assessing protein quality is crucial for understanding its nutritional benefits, which are determined by factors such as essential amino acid composition, digestibility and bioavailability (Eggum, 1991). Various measurement scales and techniques are employed for evaluating protein quality, including the protein efficiency ratio (PER), biological value, net protein utilization and protein digestibility corrected amino acid score. The protein efficiency ratio assesses protein effectiveness by measuring animal growth in rats fed a test protein, comparing the weight gain to a standard value of 2.7, which signifies excellent protein quality but lacks direct relevance to human growth needs. Biological value evaluates protein quality by calculating nitrogen utilization for tissue formation, often favouring animal sources due to their higher essential amino acid content. As mentioned in the report (Eggum, 1991), Net protein utilization (NPU) measures nitrogen retention, while the protein digestibility corrected amino acid score adjusts for faecal digestibility, providing a comprehensive assessment of protein quality (Hoffman and Falvo, 2004).

According to the U.S. Dairy Export Council's Reference Manual for U.S. Whey Products (protein quality rankings were sourced from various studies. PER values ranged from 0.8 for wheat gluten to 3.9 for egg protein. Variations in BV scores were observed, with whey protein having the highest at 104 and black beans the lowest at 0. Net protein utilization (NPU) ranged from 0.52 for peanuts to 94 for egg protein. Furthermore, the PDCAAS consistently registered at a high 1.00 for most proteins, indicative of complete amino acid profiles. Beef, casein, egg and milk proteins consistently demonstrated high scores across all metrics, while black beans and peanuts exhibited lower values. Soy protein displayed moderate scores across all metrics, while wheat gluten scored lower on BV and NPU. This data offers valuable insights into the nutritional quality of diverse protein sources.

The utilization of milk and its derivatives in the food industry has a long-standing tradition owing to their exceptional nutritional profile and flavor. With advancements in milk processing technologies, there's been a proliferation of distinct milk derivatives catering to diverse needs within the food sector. Notably, milk proteins boast a high concentration of lysine, making them valuable complements to other protein sources lacking in this EAA, such as cereals and many plant-based foods (Smitha, 2011). Moreover, recent advancements in membrane filtration technology have enabled targeted extraction and utilization of various milk components, particularly proteins, to meet specific nutritional and functional requirements in bakery goods, formulated foods, beverages and more (Schuck et al., 2002; Fang et al., 2012).

Review of Literature

A review of commercially available whey protein categorizes it into three main types: whey protein concentrate (WPC), whey protein isolate (WPI) and whey protein hydrolysate (WPH), also known as hydrolysed whey. WPC, commonly referred to as native whey, can contain anywhere from 29% to 89% total protein per 100 g, with the remaining nutritional components largely comprising carbohydrates, predominantly lactose and lipids. Recent studies, such as one conducted by Fouillet et al. (2001), have examined the nutrient compositions and effects on post-exercise protein balance. Additionally, research by Elliot et al. (2006) suggests that the inclusion of milk fat may yield slightly positive outcomes compared to fat-free alternatives, as observed in comparisons between whole and fat-free milk. These findings underscore the nuanced considerations in optimizing protein intake for exercise recovery and overall nutritional benefit.

Milk Protein Concentrate (MPC) stands out as a significant dairy product, offering varying protein concentrations ranging from 42 to 85 percent. Common variants like MPC-42, MPC-70, MPC-80 and MPC-85 denote their respective protein content percentages. The composition of MPCs, including fat, protein, ash and lactose, varies depending on the specific type and processing methods employed, with fat content typically ranging from 1-2 percent and protein content from 42.0-86.7 percent. Lactose content spans from 0.50-45.5 percent. These MPCs find application across a spectrum of food products, as outlined in table 2.8.1, reflecting their versatility and importance in meeting diverse nutritional and functional demands (Cessna, 2004).

A review of whey protein concentrates highlights WPC-70 and WPC-80 as prevalent forms, containing 70% and 80% protein concentrations, respectively. These are favoured in sports supplements due to current raw material pricing and potentially improved taste compared to WPI or various forms of WPH as noted by Whetstine et al. (2005).

Despite their popularity, paradoxically, much of the research on whey protein has centred on WPI or WPH. WPI, comprising $\geq 90\%$ total protein with minimal lactose and lipids, holds significance for individuals with lactose intolerance, particularly when high daily whey or dairy product intake is involved. Additionally, WPI may offer advantages over WPC in very-low-carbohydrate (ketogenic) diets, as suggested by Hulmi et al. (2010). These findings emphasize the practical considerations and potential benefits of different whey protein forms in dietary and supplementation strategies.

Review of Literature

Whey protein, particularly whey isolate, is renowned for its high quality among available proteins, being rapidly digested and boasting elevated levels of essential amino acids while containing minimal lactose (typically less than 1.0%). In contrast, casein, constituting approximately 80% of bovine milk protein, is digested more slowly and contains around 10–20% fewer EAAs per gram of protein. A significant study from 2006 revealed that 13 recreational bodybuilders, who supplemented their diet with 1.5 g of WPI per kg of body mass per day, experienced notable gains in lean mass (approximately 4.2 kg) and strength (around 23 kg in the squat, 30 kg in the bench press and 15 kg in the lat pull-down) compared to those ingesting an equivalent amount of casein over a supervised 10-week resistance training program (Cribb, et al., 2006). Additionally, individuals in the whey isolate group saw a reduction of 1.4 kg in body fat, while the casein group did not experience any change. It's worth mentioning that the total protein dose was divided into four equal servings and consumed throughout the day (i.e., at breakfast, lunch, post-training and dinner). Thus, Whey isolate supplementation during resistance exercise training yields significantly greater gains in lean mass and strength and considerably greater reduction in body fat compared to casein supplementation (Cribb, et al., 2006).

Whey, the liquid residue from cheese manufacturing after coagulation and curd removal, is the source of whey proteins, separated and purified through various methods to obtain different concentrations (Shankar and Bansal, 2013). Whey comprises one of the two main protein groups in milk, representing 20% of milk protein, with casein constituting the rest (Hayes and Cribb, 2008). Whey's components provide ample essential and branched-chain amino acids, quickly elevating plasma amino acid levels, crucial for preserving muscle mass. Whey protein exists in three main forms: whey protein, whey protein concentrate and whey protein isolate. Whey concentrate contains more biologically active components and proteins, while whey isolates boast protein concentrations of 90% or higher (Hoffman and Falvo, 2004). Processing whey concentrate into isolate involves significant fat and lactose removal, rendering it safe for lactose-intolerant individuals. Hydrolyzed whey protein (HWP), predigested for faster amino acid release, enhances bioavailability and muscle protein synthesis.

Review of Literature

Milk protein concentrates contain both casein and whey proteins, available in concentrations ranging from 42% to 85% (Hoffman and Falvo, 2004). While ultrafiltration is the preferred method for production, they can also be obtained by precipitating proteins from milk or dry blending milk proteins with other components. Compared to skim or whole milk powder, milk protein concentrates offer higher protein and lower lactose content (Shankar and Bansal, 2013).

Casein, existing in milk as micelles, benefits athletes by sustaining increased protein synthesis for prolonged periods when supplemented. Soybean derivatives, categorized into flour, concentrates and isolates, offer varying protein concentrations and refining levels. Egg albumin, low in fat and carbohydrates, provides high biological value protein, digested slowly for prolonged amino acid release, enhancing muscle strength as demonstrated in studies (Hida et al., 2012).

Pea protein isolate (PPI) is derived from peas (*Pisum sativum*) and boasts a protein content of 85 per cent, making it particularly rich in essential BCAA such as leucine, isoleucine and valine, which are crucial for muscle protein synthesis (Stark et al., 2012). Babault et al. (2015) discovered that consuming 25 g of protein twice daily over a 12-week training period can yield health benefits, suggesting that pea protein may enhance muscle protein synthesis when consumed immediately after resistance exercises (Phillips et al., 1997).

Soy stands out as the most widely utilized vegetable protein source. Originating from the legume family, soybeans have been documented in China as far back as 2838 B.C., where they were esteemed for their nutritional value alongside wheat, barley and rice. While soy gained popularity in numerous countries, its nutritional significance wasn't recognized in the United States until the 1920s (Hasler, 2002). Despite potential cultural influences, the lower protein quality rating on the PER scale may have affected protein consumption patterns. However, when assessed using the more precise PDCAAS scale, soy protein was found to be on par with animal protein, achieving a perfect score of 1.0 (Hasler, 2002). Soy's high quality makes it an appealing option for individuals seeking non-animal protein sources or those with lactose intolerance. As a complete protein rich in BCAAs, soy offers numerous reported health and performance benefits, including the potential to reduce plasma lipid profiles, increase LDL-cholesterol oxidation and lower blood pressure. However, further research is required to substantiate these claims (Hoffman and Falvo, 2004).

Review of Literature

The soybean can be categorized into three main types: flour, concentrates and isolates. Soy flour comes in various forms, including natural or full-fat (containing natural oils), defatted (with oils removed) and lecithinated (with added lecithin) varieties (Hasler, 2002). Among these, soy flour is the least refined and is commonly used in baked goods. Textured soy flour, another product derived from soy flour, serves primarily as a meat extender in food processing applications.

The high-protein bars commonly found in stores typically feature a limited variety of proteins sourced from both plants (primarily soy protein concentrates (SPC) and isolates) and animals (particularly whey protein concentrates and isolates). Incorporating whey protein hydrolysates into these bars has been shown to maintain their soft structure, albeit with a potential slight bitter aftertaste (Hogan et al., 2012). Whey derivatives, including concentrates and isolates, are widely utilized in the food industry due to their high nutritional value, desirable sensory properties (such as a milk flavor) and excellent functional attributes (Weeks, 2007). Nevertheless, there is growing interest in alternative protein sources, notably plant proteins, which aim to rival the physicochemical, textural and nutritional characteristics of commonly used whey protein concentrates (Wang and Xiong, 2019).

Soy protein isolate (SPI), typically containing around 90% protein, is derived from defatted soy meal through the removal of most fats and carbohydrates (Seyam, 1983). Initially, soybeans are processed into oil and defatted meal, commonly used as animal feed. A portion of this meal is further refined into various food ingredients, including soy flour, protein concentrate, isolate and textured protein (Franzen and Kinsella, 1976). SPI is often blended with other components like vitamins, minerals and flavors to create soy protein shake powder (Seyam, 1983).

Table 2.8.1 Milk Protein Concentrate (MPC) Variants and Their Composition with Suggested Uses

Product	Protein (%)	Fat (%)	Ash (%)	Lactose (%)	Suggested Uses
MPC 42	42.0	2.0	8.0	45.5	Frozen desserts, non-fat dry milk replacement, bakery and confection applications, standardization cheese milk
MPC 75	74.8	2.0	10.5	8.5	Frozen desserts, nutritional beverage powders, bakery and confection applications, non-standardized cheese products, cheese milk standardization
MPC 80	79.8	2.5	8.5	5.5	Sports nutrition drinks and bars, aged care products, hospital rehabilitation products
MPC 85	84.8	2.5	8.5	0.5	Sports nutrition drinks and bars, aged care products, hospital rehabilitation products
MPC 90	86.7	1.6	7.1	1.0	Products with a lactose- and sugar-free claim, nutritional foods, beverages, frozen desserts

Source: Cessna, (2004)

Advancements in food technology have broadened the range of soy products available, including concentrates, isolates and extruded-expanded products, leading to increased adoption in technologically advanced regions (Young et al., 1979). The production process for SPI involves three main steps (Moure et al., 2006): Firstly, soy flakes are mixed with water under alkaline conditions (pH 6.8-10, temperature 27-66°C) using substances like sodium hydroxide, allowing proteins and oligosaccharides to dissolve. The resulting protein solution is separated from insoluble residue through

centrifugation. Secondly, the supernatant containing proteins and sugars is acidified to an isoelectric pH of 4.5 using hydrochloric acid, causing protein precipitation as curd. Finally, the precipitated protein's solubility is restored by neutralizing to a pH of 6.5-7.0, either through redilution with water or spray drying in its acidic form, before being packaged (Lusas et al., 1995).

The study conducted by Xu et al. (2023) explored the utilization of soy protein isolate (SPI) extruded at various temperatures in the formulation of high-protein nutrition bars (HPNBs) to address the issue of hardening during storage. Their findings revealed that incorporating extruded SPI led to notably softer HPNBs with higher sensory acceptance throughout a 45-day storage period at 37 °C, compared to HPNBs made with unextruded SPI. Interestingly, the study observed no significant differences in hardness and total color change among HPNBs produced with varying extrusion temperatures after the storage period. Correlation analysis indicated that HPNBs formulated with SPI extruded at 50 °C exhibited the most favorable physicochemical properties. This research offers a promising approach to mitigate the hardening of HPNBs during their shelf life or extended storage durations.

In dairy applications, vegetable protein isolates have emerged as highly suitable options due to their finely dispersed particle size and excellent dispersibility. Emphasizing the importance of functional properties such as emulsification, emulsifying stability, color and flavour/odour, Johnson (1975) underscores their critical role. Soy protein ingredients have notably found application in emulsion-type cheeses, where they can effectively substitute up to 50.0% of sodium caseinate. Additionally, both full-fat and defatted soy flours have demonstrated success as primary components, offering cost-effective replacements for milk solids in various human beverage formulations, as discussed by Ohr (1997) and Singh et al. (2008). These findings highlight the versatility and potential of vegetable protein isolates, particularly soy, in enhancing dairy product formulations and meeting consumer demands.

In exploring the use of full-fat soya flour (FFSF) as a viable alternative in the production of 'Milk chocolate' through the panning process, significant potential emerges. Research by Gojiya and Patel (1998) reveals that FFSF exhibits promise in replacing up to 21.6% of milk solids in the chocolate formulation. The resulting chocolate not only proved to be more cost-effective but also boasted a higher protein content (12.16% compared to

10.16% in the control) and calorie count. Notably, the cost efficiency of FFSSF, being eight times cheaper than milk solids, contributed to overall cost reduction in production. These findings underscore the practicality and benefits of incorporating FFSSF into chocolate manufacturing processes, highlighting its ability to enhance nutritional profiles while reducing production expenses.

In a survey conducted by Deota and Chandorkar (2013), nine protein sources were identified, with only one (11.1%) originating from vegetarian sources, specifically Soy protein isolate. The majority, comprising seven (77.8%), were derived from milk and one (11.1%) was egg-based. Whey protein holds a prominent position in the sports nutrition market due to its perceived protein quality and amino acid profile. It contains high levels of essential amino acids, particularly leucine and is known for its rapid digestibility (Devries and Phillips, 2015).

Value for Cost in Relation to Protein Content and Serving Size

Dar et al. (2023) conducted a study in Lahore, Pakistan, exploring the feasibility of producing affordable snack bars enriched with locally sourced ingredients such as roasted black chickpeas, nuts and underutilized seeds. Proximate analysis revealed favorable nutrient content, with the bars providing ample macronutrients. Sensory evaluation affirmed their acceptability among experts. Notably, the cost analysis exhibited significant savings, with each bar costing Rs. 69.65, compared to Rs. 130 for commercial alternatives. Despite the inclusion of premium ingredients like roasted black chickpeas, dates and dark chocolate, the overall cost remained competitive, highlighting the economic viability and nutritional advantages of utilizing local resources in snack bar formulation.

While the manufacturing process for snack bars is generally straightforward, the challenge lies in integrating significant quantities of functional components. This difficulty arises from the unique characteristics of these components and their interactions with ingredients like corn syrup. Furthermore, these functional additives can adversely affect sensory attributes such as texture and taste, as well as physical properties like water activity (Gunyaphan, 2020).

Review of Literature

As mentioned by Ho et al. (2016), energy bars, often called snack bars, are known for their portioned servings, ease of use and health advantages. Svisco et al. (2019) have underlined that they are often sold as "ready-to-eat" formulations, usually containing whole cereal grains. The main calorie sources in these dense, portable bars include fats, proteins and carbs, which can boost energy levels and even take the place of a meal. Tiwari (2019) state that 45–80 gram of energy bars contains around 200–300 kcal (840–1,300 kJ), 3–9 g of fat, 7–15 g of protein and 20–40 g of carbs.

Notwithstanding the vast array of high-protein bars that are currently on the market, they generally contain low-weight polyhydroxy compounds (like glycerol), sugars, alcohols (like sorbitol), lipids (like palm oil), vitamins and minerals as minor ingredients, along with minimal water content ($a_w \leq 0.65$) (Imtiaz et al., 2012). But creating these bars is still difficult because of interactions between ingredients when they are mixed, which leads to a product that has a short shelf life and a constantly shifting sensory character (Loveday et al., 2009, 2010). Problems like product hardening or the gradual development of an unwanted rough texture are the causes of this constraint (Salam and Shibiny, 2020; Zhou et al., 2008). Various physical or chemical changes during storage, such as Maillard reactions, sugar crystallisation and molecular migrations, can cause texture hardening. Addressing these challenges requires researchers and producers to focus on modifying the product formula to mitigate bar hardening over time and focusing on the acceptability and sensory attributes of the bars (Gray et al., 2003).

In their 2020 study, Gill and Singh explored the diversity in serving sizes and pricing per unit mass among energy bars. They observed a wide variation in serving sizes, spanning from 22 to 75 g, with the most prevalent sizes falling within the range of 30 to 40 g. Price per gram exhibited a considerable range, ranging from Rs. 0.45 to 4.39. Additionally, the researchers noted that common retail packaging typically contained two to twelve units per box. Furthermore, their investigation revealed that a single brand could offer between one to six or more variants, reflecting the extensive variety within the energy bar market. These findings underscore the significant variability in product offerings and pricing strategies within the energy bar industry, emphasizing the importance of consumer choice and market segmentation.

Review of Literature

A small number of studies that examined low-protein, high-fiber and carbohydrate bars were also reviewed. In a study conducted by Giri and Mridula (2016), the formulation and evaluation of fiber-rich food bars were examined. The results indicated that these bars were more affordable than other options on the market; the created bars cost Rs 7 per 32g/bar, which was somewhat more than the control sample's Rs 6.5 per 32g/bar. High-energy snack bars made from red sorghum flakes were studied by Singh et al. (2021) to assess their cost-effectiveness, with manufacturing costs estimated at Rs. 31 per unit (50g), which included a 20% profit margin and 10% depreciation. These costs were still less than market rates, which ranged from Rs. 50 to Rs. 104. Comparing the cost of production of composite sports bars to commercial counterparts, Sobana (2017) found that the developed millet-based composite sports bar was more cost-effective and affordable, with a total production cost of Rs. 44.50 per 100g, or Rs. 14.80 per 40g serving. Together, these studies highlight the financial viability and possible cost reductions linked to creative food bar (high energy, low protein) compositions that provide customers both financial and health benefits.

The majority of energy bars on the market are priced at a premium, primarily appealing to the middle and upper-class demographics. Despite the availability of a few budget-friendly options, numerous brands opt for costly ingredients like pumpkin seeds, quinoa and blueberries in their energy bar formulations. However, this approach proves to be economically unsustainable, given the abundance of equally nutritious yet more cost-effective alternatives. Consequently, such products cater to high-income consumers, leaving those from lower-income brackets underserved. Hence, there is a pressing need to develop protein-rich products that are not only affordable but also fortified with essential micronutrients to address broader nutritional requirements (Gill and Singh, 2020, as surveyed in 2019).

Innovation in the Sports Food Industry

Sports foods are specialized products intended for individuals engaged in regular physical activity, aimed at enhancing their nutritional intake, overall health, performance, muscle development and post-exercise recovery (Arenas-Jal et al., 2020). Those who engage in physical exercise at least three times a week, with sessions lasting 30 minutes or more and involve moderate-intensity activities are typically categorized as "sports people". These individuals can benefit from consuming a well-balanced diet

to meet their energy requirements and improve their capacity to adapt to physical training. Sports nutrition pertains to the specific nutrients found in sports-related foods, which are crucial for supporting the physical and metabolic demands of athletes or bodybuilders regularly engaging in physical exercise, as well as for maintaining overall physical health and athletic performance (McArdle, 2018).

In their study, Cui et al. (2022) highlights that sports foods come in a variety of forms, including beverages, solids, semi-solids and supplements and that they provide fundamental basic nutrients and functional aspects. The sector gains from growing markets, improved technology and more investment, but it also has to deal with issues including inadequate research, safety concerns and stagnating innovation. The growing interest in health management and the popularity of sports are driven by economic advancement and increased quality of life, which encourages innovation in the sports food industry.

Dumbrava et al. (2021) aimed to develop an innovative sugar-free protein bar in two variants: one vegan with soy flour (PBAS) and the other with whey powder (PBAW). Both variants shared a base comprising peanut butter, Stevia rebaudiana leaf powder, carob, oat flakes and inactive yeast flakes. The study also sought to evaluate the total polyphenol content and antioxidant capacity of the protein bars compared to their raw materials, alongside determining the proximate composition and energy value of the final products. Results indicated that Stevia rebaudiana exhibited the highest total polyphenol content and antioxidant activity among the raw materials. The PBAS variant demonstrated superior polyphenol content and antioxidant activity compared to PBAW, with the former also being cholesterol-free and having a higher caloric intake, while the latter boasted higher protein content.

Alfheaid et al. (2023) investigated the feasibility of producing unique high-energy and high-protein bars using *Sukkari* dates or a fruit mixture as a base. *Sukkari* dates were chosen due to their nutrient density, convenience, affordability and role as a healthier sugar alternative. The study evaluated attributes such as appearance, taste, color, odour, texture, mouthfeel and overall acceptability of the bars. Sensory evaluation data indicated a significant preference for *Sukkari* date bars over those based on fruits. Through analysis and comparison of different ingredients, the study strongly recommends the use of dates instead of fruits for making high-energy and protein bars. However, it suggests further investigation into the rheological properties and shelf-life stability of the bars presented.

2.9 Extruded foods

Food extrusion processing involves applying pressure to a blend of food ingredients, such as maize, soy, wheat, sorghum, among others, causing them to flow while being mixed, heated and sheared. This mixture is then passed through a die or perforated plate specifically designed for shaping the food with the desired ingredients. This method produces a unique cooked food product that aligns with cultural preferences and is enriched with targeted nutrients. Through high temperature, short time (HTST) heating, heat-sensitive nutrients are preserved, while protein and starch digestibility are enhanced and anti-nutrients like trypsin inhibitors, gossypol, hemagglutinins and undesirable enzymes such as lipases, lipoxidases and microorganisms are eliminated (Egal and Oldewage-Theron, 2020; Riaz, 2000). Proteins also play a crucial role in extrusion processing for both structural integrity and nutritional value. Lower protein concentrations result in reduced visibility of any structural or textural features formed by the protein within the final product. Achieving desired texturization typically requires a minimum protein level of 30% (Twombly, 2020).

Extrusion processing has emerged as a highly efficient and eco-friendly method for producing a wide array of food items, gaining increasing popularity. It is favoured for its continuous operation, delivering high productivity with rapid cooking times, effectively eliminating harmful microbes and anti-nutrient enzymes. This results in nutrient-rich products with extended shelf life, addressing both nutritional needs and food security concerns (Filli et al., 2014). While initial investment costs can be substantial and meticulous attention to process parameters is necessary to prevent the formation of undesirable substances, these drawbacks are outweighed by the numerous benefits (Filli et al., 2014).

Moscicki and van Zuilichem (2011) highlighted that extrusion-cooking processes operate under HTST conditions, reaching feed temperatures of up to 200°C within a short residence time of approximately 5 to 10 seconds, with pressures reaching up to 20 MPa. The process involves mixing, compressing, melting and plasticizing the feed. Extrusion at temperatures ranging from 100°C to 180°C for brief durations helps retain heat-sensitive food ingredients, ensuring good product quality. Stable and consistent feeding into the extruder is crucial for product uniformity, as inconsistent flow rates

lead to variations in size, texture and shape. Screw speed influences residence time distribution, barrel fill degree and shear stress on the material. Moisture content typically ranges between 14% and 20%, with screw speeds exceeding 250 rpm common for ready-to-eat cereals, snacks and pet foods (Harper, 1994).

Recent research has explored extrusion cooking for various food products such as snack foods, pasta, breakfast cereals, baby foods and pet foods, enhancing nutrient digestibility and bioavailability. Studies on extrusion processing of cereal and pulse blends aim to produce high-fiber, high-protein, low-fat extruded products (Gu et al., 2008).

2.10 Extruded sports foods

Corn, rice, wheat and oats are prevalent ingredients in the food industry. While refined flour versions of these grains are frequently employed, there is a growing trend towards utilizing whole-grain flours due to their recognized health advantages (Ek et al., 2020).

Maize is a rich source of carbohydrates, fiber and essential minerals such as potassium, phosphorus, magnesium and calcium. Maize flour typically contains 64% carbohydrates, 8.8% protein, 3.77% fat, 12.24 % total fiber and 1.17% ash (IFCT, Longvah et al., 2017). Due to its high starch content, maize has historically been a key ingredient in the production of various ready-to-eat (RTE) products through extrusion cooking. Many commercially available extruded expanded products are made predominantly from maize grits, owing to their low cost, abundance and high expansion properties. However, maize alone offers a limited nutrient profile, with relatively low protein and dietary fiber content (Onwulata et al., 2001). To address this limitation, researchers have incorporated maize into composite blends for developing extruded or novel products (Patel et al., 2004; Li et al., 2005; Sawant et al., 2013).

Finger millet is recognized for its nutraceutical value, serving as a rich source of protein, iron, magnesium, calcium, phosphorus, fiber, polyphenols and vitamins. It has the highest calcium content among cereals and the highest iodine content among food grains. The proximate composition of finger millet includes 66.82 % carbohydrates, 7.16 % protein, 1.92% fat, 2.04 % ash and 11.18 % dietary fiber (IFCT, Longvah et al., 2017). Various researchers have utilized finger millet in the development of extruded

products in combination with other ingredients (Ushakumari et al., 2007; Devi and Sangeetha, 2013; Ramachandra and Thejaswani, 2014). Balasubramanian et al. (2012) developed extruded snack foods using a flour blend of finger millet, pearl millet and soybean, while Seth and Rajamanickam (2012) created high-quality extrudates with a blend of finger millet, sorghum, soy and rice. Sawant et al. (2013) successfully produced acceptable RTE extrudates with an expansion ratio of 3.5 using a composite blend of brown finger millet, maize, rice and full-fat soy.

As consumers increasingly seek nutritious alternatives in their food choices, ancient grains have garnered attention. These grains, often consumed for centuries due to their local availability and nutritional value, offer protein levels surpassing conventional cereal grains, making them appealing substitutes. Their health benefits are often attributed to their consumption in whole-grain form. Examples of such ancient grains include quinoa, sorghum, amaranth, millet and teff (Ek et al., 2020).

In a recent study conducted by Rangira et al., (2020), the extrusion characteristics of various whole bean flours were systematically investigated. Four types of whole bean flours, including faba, lima, pinto and red kidney beans, were extruded under different conditions. The study examined the effects of barrel temperature (120°C, 140°C and 160°C), moisture content (17%, 21% and 25%) and screw speed (150, 200 and 250 rpm) using a corotating twin-screw extruder (TSE). Results revealed that faba bean extrudates exhibited a significantly higher expansion ratio (2.24) compared to other beans, despite faba bean having higher protein and crude fiber contents. The study concluded that both starch and protein functionalities significantly influence the extrusion expansion process.

2.11 Common Ingredients in Food Bars

Peanuts are widely acknowledged as a valuable and economical source of essential nutrients encompassing proteins, carbohydrates, lipids, vitamins, minerals and fiber, all pivotal for human health. Often dubbed as the "poor man's protein," peanuts, when consumed in appropriate quantities and diverse preparations, offer a wealth of nutrients necessary for fostering growth, sustaining energy levels and warding off diseases. These legumes boast essential metal ions crucial as cofactors for various enzymes, as well as vitamins that are not naturally synthesized by the body. Additionally, they

contain polyunsaturated and monounsaturated fatty acids renowned for their ability to increase levels of HDL cholesterol, thereby promoting heart health. Moreover, peanuts provide indispensable amino acids vital for constructing proteins and carbohydrates, which serve as the primary fuel source for the body. Embracing peanuts in one's dietary regimen can provide a holistic spectrum of vital nutrients, significantly contributing to disease prevention and overall health and wellness (Settaluri et al., 2012).

Peanuts are known for their protein content, typically ranging from 26 per cent to 29 per cent, which offers high nutritional value. These proteins are cost effective and valued for their functional properties, such as emulsification and forming, as well as their nutritional benefits in diverse food products. They are also utilized in developing countries to fortify cereals, beverages and skim milk in human diets. The process of obtaining peanut protein isolate involves extracting proteins from defatted peanut cake or powder through maceration with a high salt phosphate buffer (comprising 20 mM Na₂HPO₄, 2 mM KH₂PO₄, 5.4 mM KCl, 1M NaCl, pH 7.4), followed by centrifugation. The resulting supernatant is then supplemented with (NH₄)₂SO₄ until reaching 90% saturation and the subsequent pellet is subjected to dialysis against distilled water overnight at 4°C, followed by freeze-drying (Mouécoucou, 2004). This method ensures the preparation of peanut protein isolate with high purity, suitable for various food applications, like raw materials for sports foods thereby addressing both functional and nutritional needs in food formulation.

Date fruit presents itself as a promising option for the development of snack bars, owing to its rich nutritional profile and functional properties. The exploration of dates for energy bar production dates back to the 1970s, when Kamel and Kramer (1977) initiated a pilot study utilizing dates, known for their high carbohydrate content and low protein content, to address protein shortages prevalent in certain regions with abundant date cultivation. Since then, enhancing protein content has remained a primary focus in the formulation of date-based bars.

Belonging to the Arecaceae family, date fruit (*Phoenix dactylifera*) holds significant agricultural importance, with a history spanning over 4000 years, primarily in the Middle Eastern and North African regions characterized by dry and arid climates. Cultivated for cultural, nutritional, environmental, religious and social reasons, date fruit boasts a nutritional composition primarily comprising carbohydrates, fiber and protein, with minimal fat content. Additionally, date fruit offers an array of micronutrients, including vitamins such as thiamine, riboflavin, C and E, essential minerals like potassium and magnesium and various phytochemicals. This review

provides insights into the nutritional characteristics of different date varieties cultivated worldwide, emphasizing their potential utilization in snack bar formulations. Figure 2.6.4.1 shows the graphical abstract utilization of dates into a snack bar (Barakat and Alfheaid, 2023).

Dates are recognized for their significant carbohydrate content and nutritional value, yet they lack sufficient protein. To address this deficiency, researchers have investigated the incorporation of economical and underutilized protein sources into date bars. Utilizing the optimal formulation, which includes whey protein concentrate and vetch protein isolate, date bars were prepared. This approach not only enhances the protein content of the bars but also utilizes cost-effective protein sources. This study highlights the potential for improving the nutritional profile of date bars through innovative formulations incorporating alternative protein sources (Nadeem et al., 2012).

El Sakkoti and Shamia-Beida dates underwent air drying at 70°C for 10 minutes, followed by cooling at room temperature on a wooden board to settle and eliminate rehydration. Subsequently, the cores were separated and ground using a grinder, then packaged under vacuum to prevent moisture gain. The processing line has a daily capacity of two tons of raw materials, with the dehydration step in the drying oven being the limiting factor, operating overnight to achieve the desired moisture content in the date flesh for subsequent processing steps. In another aspect, hard sweet biscuits were prepared by replacing sucrose partially with 20%, 30% and 50% of selected treatments of date powders. The remaining moisture in the biscuits exists in the form of bound water, covering the hydroxyl, hydrogen and carboxyl groups of sugars, starch, proteins, fats and fiber chains with single water molecules to inhibit oxidation. Consequently, the water activity of the dry biscuits is sufficient to prevent microbial contamination (Mubarak et al., 2022).

Rukh et al. (2021) investigated the physicochemical properties of date bars, a nutritious snack created by integrating date pit powder, a byproduct and soy protein isolate into date paste. Following ingredient optimization, date bars were formulated and subjected to analysis for physicochemical attributes, in-vitro starch and protein digestibility, antioxidant content and microbial count. The findings revealed that date bars are abundant in protein, fiber, carbohydrates and fat, exhibiting favorable digestibility characteristics. Incorporating date pit powder and soy protein isolate notably enhanced the physicochemical properties of the bars. Furthermore, the combination of these

ingredients increased the antioxidant potential and shelf stability of the date bars. Date pit powder and soy protein isolate emerged as valuable sources of carbohydrates, fiber, minerals and proteins for the production of soy date bars, which can serve as convenient ready-to-eat snacks or appetizers. Additionally, date pit powder holds potential as a functional ingredient in other food products.

Sesame seeds, commonly referred to as gingelly seeds or *til*, have a rich history as one of the oldest cultivated oilseeds globally, with India and China leading in production. Both black and white sesame seeds boast a plethora of macro and micronutrients, along with bioactive compounds like lignans and phytosterols, making them potent antioxidants. The presence of *sesamin*, *sesaminol*, myristic acid and lecithin contributes to various health benefits, including anti-inflammatory, anti-hypertensive, anti-hyperglycaemic, anti-hyperlipidaemic and anti-cancer properties. Sesame oil is recognized for its antimicrobial activity and finds extensive use in Ayurvedic practices such as *shirodhara* for relaxation. Additionally, its oil serves as a skin softener and aids in treating cracked heels. Versatile in culinary applications, sesame seeds are used as garnishes in various baked goods, while traditional Indian treats like *til-chikki* and laddoos are household favourites. Despite its widespread use, it's noteworthy that even minimal consumption of sesame seeds may trigger allergic reactions in susceptible individuals (Mohammed and Pattan, 2022).

According to data from the Indian Food Composition table (IFCT, Longvah et al., 2017), black gingelly seeds (*Sesamum indicum*) are nutritionally dense, with 100 g providing approximately 4.51 g of moisture, 19.17 g of protein, 5.78 g of ash and 43.10 g of total fat. They are also a good source of dietary fiber, offering 17.16 g per 100 g, along with 10.29 g of carbohydrates. With an energy content of around 2124 kilojoules, these seeds stand out for their high protein and fat content, as well as their notable fiber levels. Moreover, they have a moderate carbohydrate content and are relatively low in moisture. Owing to these attributes it marks as a potential superfood for athletes.

Data from Longvah et al. (2017) indicate that the moisture content of dried black raisins (*Vitis vinifera*) is about 19.69 g per 100 g. With 2.57 g of protein and 2.19 g of ash, they are comparatively low in these nutrients. With 0.34 g of total fat per 100 g, it is quite low. Still, they give about 3.92 g of dietary fibre, which is a decent quantity and 71.29 g of carbs, which make up the majority of their content. Dried black raisins have about 1279 kilojoules of energy per 100 g. These nutritional qualities show that dried black

raisins are a food heavy in carbohydrates and low in fibre, which makes them a handy and high-energy snack choice.

Various commercial carbohydrate supplements, including gels, shots, bars and chews, are commonly used by endurance athletes as a performance enhancer. But natural carbohydrate-rich diets can offer similar advantages when exercising. Sun-dried raisins and sports jellybeans were used as carbohydrate supplements during 10 K time trials and Rietschier et al. (2011) looked at the results. A 2-hour glycogen depletion session was followed by a 10-kilometer time trial for ten male cyclists participating in the study. The carbohydrate supplement given to study participants was a random combination of sun-dried raisins and sports jellybeans. Results showed no statistically significant difference in the performance outcomes between the two groups, suggesting that sun-dried raisins and sports jellybeans were equally beneficial as carbohydrate supplements during endurance activities like the 10 K time trials. This suggests that natural foods like raisins can serve as a viable alternative to commercial carbohydrate supplements for endurance athletes, offering comparable performance benefits.

Sacheck et al. (2009) conducted a study comparing the effects of three isocaloric snacks on 115 young soccer players (ages 9.01 ± 0.9). The snacks included a raisin/nut bar, a peanut butter graham bar and a rice cereal bar. After engaging in a 50-minute game of moderate to vigorous activity, the researchers found that consuming the rice cereal bar, which had high sugar content and low flavonoid levels, was associated with increased feelings of fatigue compared to the other two bars. However, there were no significant differences in reported effects between the raisin/nut bar and the peanut butter graham bar. This suggests that raisin consumption, as part of a raisin/nut bar, may have potential benefits for improving athletic performance, possibly due to its nutrient composition or other bioactive components.

The effects of commercial carbohydrate supplements and raisins on cycling performance were examined in research conducted by Kern et al. (2007). Before beginning any physical activity, the subjects (four men and four women) were randomised to receive a fixed quantity of sports gels or raisins, each of which contained one gram of carbohydrates per kg of body weight. Participants then rode at a consistent intensity for 45 minutes and then they rode in a performance capacity for 15 minutes. Because there was no discernible difference in the two groups' performance, the

researchers concluded that the work output produced by sports gels and raisins was equal. This shows that raisins can enhance exercise performance just as well as commercial carbohydrate supplements due to their natural carbohydrate content.

In a study conducted by Kalman et al. (2013), the effects of consuming isocaloric snacks of raisins versus granola bars on feelings of energy in mothers were compared over a 14-day study period. The results indicated that mothers reported a significant increase in energy levels when they consumed both raisins and granola bars as snacks. Interestingly, when comparing the two snacks, raisins were associated with higher energy scores for 13 out of 14 test days, with statistical significance ($p = 0.002$). It's noteworthy that neither snack led to a change in the subjects' weight throughout the study duration. These findings suggest that both raisins and granola bars can effectively boost feelings of energy, with raisins showing a potential advantage over granola bars in this regard among the studied population of mothers.

Chia seeds, characterized by their oval shape and smooth, shiny surface, are available in various colours including dark brown, grey, white and black. These seeds are typically small and flat, measuring approximately 2 - 2.5 mm in length, 1.2 - 1.5 mm in width and 0.8 - 1 mm in thickness (Safari et al., 2016). In terms of nutritional composition, chia seeds are rich in protein (15-25%), fat (30-33%), carbohydrates (26-41%), fiber (18-30%) and minerals (4-5%). They are also a notable source of omega-3 fatty acids, particularly linolenic acid, constituting around 17.83% (Ixtaina et al., 2008).

An optimal nutri bar was created using chia seeds and several formulations including 5%, 10%, 15% and 20% of chia seed flour were tested. In terms of nutritional quality, sensory qualities, physiochemical characteristics and storage stability, the formulation with 10% chia seed flour showed the most promise. Protein content in this formulation was $3.72 \pm 0.11\%$, crude fibre was $10.52 \pm 0.08\%$, ash was 2.0%, crude fat was $3.52 \pm 0.19\%$, carbohydrate content was $51.00 \pm 0.24\%$ and antioxidant activity was inhibited by $32.23 \pm 0.69\%$. This formulation was shown to be extremely acceptable by sensory examination. According to shelf-life tests, the nutri bars' shelf stability was increased when they were kept in low-density polyethylene bags at a temperature of 10°C. The calculated gross energy content of the chia seed nutri bar was 250.52 ± 0.63 kcal (Singh et al., 2020).

Review of Literature

Malt, a natural food product, is derived from the germination of cereal grains and pulses. The process of malting involves three key steps: steeping, germination and kilning, each of which can be modified to yield various types of malt. Among these, barley malt stands out as the most prevalent, primarily utilized in the brewing of beer. Additionally, barley malts find applications in the production of spirits, vinegar, bread, breakfast cereals and several other minor products (Izydorczyk et al., 2000).

Barley malt extract has been acknowledged as a very effective antioxidant source, exhibiting strong efficacy in both in vitro and in vivo settings (Van, 2016). Barley malt has been used more and more as an addition in the production of functional meals because of its high antioxidant content (Qingming et al., 2010). Barley malt germination enhances the activation of its enzymes, which is especially advantageous for starch analysis. Research has indicated that malt germination produces an extract that is more powerful than ordinary barley extract (Duke and Henson, 2008). Additionally, the barley malt extract that is derived from kilning shows increased enzymatic activity and attains more favourable features (Aniche and Palmer, 1990). According to Qingming et al. (2010), the kilning procedure may help increase barley malt's antioxidant efficacy and lower oxidative stress activity.

Confectioner's glucose, another name for glucose syrup, is a syrup made from starch that has been hydrolysed. While the glucose syrup used in industrial fermentation usually comprises more than 90% glucose, the types utilised in confectionery items vary in their grade and contain different amounts of glucose, maltose and higher oligosaccharides. Usually, these syrups have a glucose content of 10–43%. Glucose syrup is used in culinary applications to improve texture, add volume and sweeten. Corn syrup may be processed into high fructose corn syrup, a sweeter product, using an enzymatic process that turns part of the glucose into fructose. Low-DE glucose syrup has the following benefits: body, cohesiveness, foam stability, reduced sucrose crystallisation and viscosity (Hull, 2010).

Theobroma cacao fruit is the source of the beans used to extract cocoa solids. With their petite, flattish form and purple colour, Forastero beans account for most of the world's production. Currently, production of Criollo is less prevalent than that of *Trinitario*, a hybrid of *Criollo* and *Forastero* valued for its flavour profile that accounts for around 3% of global output. Forastero grows significantly; it is mostly grown in Brazil and West Africa and is known by the trade names bulk or basic cocoa. Notable for its flavour

characteristics, criollo is mostly grown in Central and South America. Currently, more than 70% of the cocoa produced worldwide is produced in West Africa (Amoye, 2006).

The nutritional composition of various types of chocolate, including dark chocolate, milk chocolate and white chocolate, was analyzed. Dark chocolate was found to have the highest percentage of carbohydrates at 58.3%, followed by white chocolate at 56.9% and milk chocolate at 63.5%. Regarding fat content, white chocolate exhibited the highest percentage at 30.9%, closely followed by milk chocolate at 30.7%, while dark chocolate contained the least fat at 28.0%. Protein content remained relatively consistent across all three types, with dark chocolate having the highest percentage at 5.0%, followed by milk chocolate at 7.7% and white chocolate at 8.0%. These variations in nutritional composition distinguish the different types of chocolate, with dark chocolate generally having lower fat content and higher protein content compared to milk and white chocolate (Chan et al., 2012).

2.12 RSM- Response Surface Methodology

The integration of technology and mathematical techniques has become crucial in addressing scientific challenges in both educational and research settings (Luneeva and Zakirova, 2017). With analytical instruments generating vast amounts of data and numerous factors affecting experimental results' complexity, employing experimental design, a chemometrics method, proves to be optimal for data optimization (Miller and Miller, 2010). Experimental design aids in statistically identifying, designing and evaluating experimental factors (Miller and Miller, 2010; Candiotti et al., 2014). RSM, a specialized form of experimental design, combines mathematical and statistical techniques to optimize product designs by considering multiple variables' impact (Myers et al., 2009). RSM surpasses traditional one-variable-at-a-time optimization by analysing interactive effects among variables, thereby reducing ineffective time and reagent usage in research projects (Bezerra et al., 2008). A summary of the most popular experiment designs for optimisation studies is shown in table 2.12.1.

Table 2.12.1 Comparison of Experimental Design Characteristics for RSM Optimization

Design	Factor Levels	Number of Experiments	RSM Characteristics
Factorial Design (FD)	Two-level full factorial (2-FFD)	$2 \leq k \leq 5$	$2k$ or $2k+1$ (considering replicates)
Factorial Design (FD)	Two-level fractional factorial	> 4	$2k-p$
Factorial Design (FD)	Three-level full factorial (3-FFD)	3	$3k$
Central Composite Design (CCD)	5	$2k + 2k + C_p$	All factors are studied in five levels ($-\alpha, -1, 0, +1, +\alpha$). α -values can be calculated using the formula $\alpha = 2(k-p)/4$.
Box–Behnken Design (BBD)	3	$2k(k-1) + C_p$	All factors should be adjusted to three levels ($-1, 0, +1$). No factorial or extreme points.
Doehlert Design (DD)	Depend on each factor	$K^2 + k + C_p$	Factor levels vary for each factor.

Source: Riswanto et al., (2019)

The food industry wants to increase system performance and process effectiveness without raising prices or lengthening turnaround times. The widely used method of optimisation is essentially concerned with determining the conditions under which a system produces its optimal result (Baş and Boyacı, 2007). In the past, optimisation in food processing usually required determining how changing one parameter would affect other parameters remaining unchanged. Nevertheless, this approach does not take into consideration the interaction effects between variables and does not offer a thorough comprehension of all the components' combined influence on the answer. In addition, it requires a lot of trials, which adds to the costs and time required (Baş and Boyacı, 2007; Bezerra et al., 2008).

To address these challenges, optimization studies often employ multivariate statistical methods. Among these, RSM stands out as the most prevalent technique in optimizing food processes (Baş and Boyacı, 2007). It comprises statistical and mathematical methods that fit a polynomial model to data, aiming to characterize the behaviour of a dataset and make statistical predictions. This approach is particularly useful in optimizing, designing, developing and enhancing processes influenced by multiple variables (Ghorbannezhad et al., 2016; Kaushik et al., 2006). Using statistical and mathematical methods, it aids in optimising the amounts of independent variables for the intended product. The different response surface approach designs are central, composite, box-behnken, one factor, miscellaneous, optimum (custom), user-defined and historical data, according to the Design Expert (9.0) programme (Gupta, 2014).

However, before applying RSM, selecting the appropriate experimental design is crucial to determine the treatments within the experimental region. Experimental designs suitable for quadratic response surfaces, such as three-level factorial, central composite and Box-Behnken designs, are commonly employed for this purpose (Bruns et al., 2006). Overall, RSM proves to be a fitting and widely utilized approach for optimizing processes within the food industry.

2.13 RSM-CCRD (Central Composite Rota Table Design)

Central Composite Design (CCD) is a widely used experimental design in Response Surface Methodology (RSM) for estimating second-order (quadratic) response surfaces, introduced by Box and Wilson in 1951 (Tanyildizi et al., 2009; Borror, 2002). It is favoured by statisticians and researchers for various response surface analysis due to its effectiveness in process optimization (Borror, 2002). CCD offers a balanced approach for sequential experimentation, providing sufficient information for testing lack of fit without requiring an excessively large number of design points (Demirel and Kayan, 2012). This design consists of three groups of design points: two-level factorial or fractional factorial design points, axial points (also known as 'star' or 'alpha' points) and centre points, which are used to estimate coefficients of the quadratic model. CCD is particularly economical in obtaining maximum information with minimum experiments, making it a preferred method among RSM experimental designs for variables like mixing time (Walia et al., 2013). The optimization process with CCD typically involves three main steps: conducting statistically designed experiments, estimating coefficients in a mathematical model and predicting the response while assessing the model's adequacy (Namdeti and Pulipati, 2013).

Optimization of food formulation using RSM

Gupta et al. (2014) employed RSM and CCD to optimize an instant kheer mix for high protein content and overall acceptability. Various formulations were tested and the best variant was chosen based on sensory evaluation. Process variables, including cowpea quantity, cowpea soaking time and malted wheat flour amount, were adjusted. The optimized recipe contained 12g cowpea, soaked for 4 hours and 5.01g malted wheat flour, yielding 10.273g protein, 0.076g crude fiber and an overall acceptability rating of 8.052. ANOVA results indicated significant effects of process variables, particularly on protein content ($p < 0.05$) and regression coefficients suggested a good model fit. The optimized mix exhibited high protein content and favorable sensory attributes.

Using RSM, Wadikar and Premavalli (2012) developed a ready-to-eat appetiser made of cumin and natural components. The product had a 9-month shelf life at 37°C and great sensory acceptability. Wadikar et al. (2010) optimised appetisers using RSM and CCRD in different research. They paid particular attention to quality criteria and active component variables including acidity, sugar and sensory acceptability score. The final products had around 80 calories per 20 g and had 7.8–9.8% fat, 6.5–7.9% protein and 72–73% carbohydrates.

Jayabalan and Karthikeyan (2013) utilized Response Surface Methodology (RSM) to optimize the ingredients—aloe vera juice (800-1200 ml), sugar (800-1200 g/kg), pectin (35-60 g/kg) and citric acid (20-40 ml)—for aloe vera jam production. The model demonstrated a significant fit ($p < 0.05$) with satisfactory correlation between actual and predicted values. The jam produced under these optimal conditions was further evaluated for sensory attributes and the results were compared with the predictions obtained from RSM. The optimized factor levels for the highest acceptability were determined using the statistical model. Subsequently, sensory analysis, including evaluation of color, taste, aroma and texture, was conducted on the aloe vera jam produced under the optimized conditions. The optimum composition for the best sensory score was found to be aloe vera juice 990 ml, sugar 1022 g/kg, pectin 50.3 g/kg and citric acid 28.2 ml. This study stands out as the only available study where RSM was used as a tool to optimize ingredients for a product, specifically for assessing sensory acceptability.

Optimization of Food Bars using RSM

In order to optimise the components for the creation of kokum fruit bars, Bafna and Manimehalai (2014) used RSM inside a BBD framework, paying particular attention to texture, general acceptability and calcium content. They discovered throughout their investigation that the two most important variables, which had a major impact on all dependent variables, were sugar and milk powder. They found that 50g of pulp, 40g of sugar and 9.39g of milk powder were the ideal proportions of ingredients for the fruit bar when the pulp content was held constant. The study's high texture (0.8298), overall acceptability (0.9239) and calcium content (0.9842) coefficients of determination (R^2) demonstrate the model's resilience in making predictions. This study highlights how RSM may be used to optimise food formulations and offers insightful information for the creation of kokum fruit bars.

Nadeem et al. (2012) conducted a study aimed at formulating a nourishing date bar with commercial appeal, particularly targeting school children's nutritional needs. The study employed RSM to optimize the protein content of the date bars, utilizing economical and underutilized sources such as whey protein concentrate and vetch protein isolates. Through a CCD with two variables and three levels for each variable, fourteen date bar treatments were generated and analyzed for their nutritional profile. The proximate composition of the date bars was shown to be greatly improved by the inclusion of whey protein concentrate and vetch protein isolates, which also improved the bars' texture, taste and protein content. In particular, adding 4.35% vetch protein isolates and 6.05% whey protein concentrate produced significant gains without sacrificing sensory qualities over storage. The study provides important insights for creating food items with enhanced nutrition by highlighting the effectiveness and affordability of RSM in maximising component quantities and clarifying the interacting impacts of independent factors.

In order to create a low-calorie, high-protein papaya fruit bar, Kulshrestha et al. (2012) included maltodextrin for texture enhancement, stevia as a sugar substitute and defatted soy flour for protein enrichment. Throughout trial runs, the researchers methodically adjusted the concentrations of these components using a central composite rotatable design. They then assessed the sensory attributes, such as colour, taste, body and texture, scent and overall acceptability. By using second-order mathematical models for optimisation, the research found that all answers were substantially impacted by defatted soy flour at both the linear and quadratic levels, whereas sensory ratings varied

Review of Literature

within reasonable bounds. Stevia and maltodextrin were found to notably affect taste and body and texture, with the optimal ingredient levels identified as 24.47%, 1.98% and 2.68% for defatted soy flour, stevia and maltodextrin, respectively. The study demonstrates the efficacy of using a systematic experimental design coupled with mathematical modelling for developing functional food products with improved nutritional profiles and sensory attributes.

In 2015, Kumar carried out research with the objective of improving the nutritional value of biscuits by the creation of a multigrain premix (MGP) that included 20% of each of whole barley, sorghum, chickpea, pea and defatted soy flour. The MGP showed good nutritional characteristics, including 10.13% insoluble dietary fibre, 7.38% soluble dietary fibre and 26.28% protein. The experiment optimised the MGP and wheat flour concentration to create multigrain biscuits with increased protein and dietary fibre content while maximising acceptance. This was achieved by using the CCRD of RSM. The ideal MGP and wheat flour levels, as determined via numerical optimisation, were 40g and 60g, respectively. Comparing these proportions to control biscuits, the protein content (16.61%), soluble fibre (2.57%) and insoluble fibre (6.67%) of the biscuits made with them were considerably greater. This study addresses the increased need for healthier snack alternatives by highlighting the efficacy of RSM in designing functional food items with enhanced nutritional profiles.

Mahawar et al. (2018) conducted a study aimed at optimizing the incorporation of *aonla* pulp into guava pulp to develop a nutritionally rich fruit bar, thus enhancing the processing value of both fruits and improving consumer nutrition. Employing RSM with a BBD, the researchers systematically varied process variables including *aonla* and guava pulp ratio, pectin concentration and drying temperature to optimize the formulation. Evaluation of physico-chemical, textural and sensory properties of the mixed fruit leather revealed significant regression models for various parameters such as titratable acidity (TA), ascorbic acid content (AA), lightness (L value), cutting force (CF), taste and overall acceptability (OAA). Increasing the proportion of *aonla* pulp resulted in elevated TA and AA but reduced L value, CF, taste and OAA. The study identified optimal conditions for the mixed *aonla*-guava bar as 40:60 (PR), 0.02% (PC) and 56°C (DT), yielding desirable characteristics. This research underscores the effectiveness of RSM in formulating functional food products with enhanced nutritional profiles while ensuring consumer acceptability.

Research on optimum ingredient amounts for the creation of a breakfast bar with peanut butter was carried out by Deepa et al. in 2021. Within the context of response surface approach, they employed a CCRD. Water activity and moisture content functioned as responses for the experimental design, whereas flaxseed, chia seed, Amaranthus Dubius and carrot powder were the selected independent variables. Flaxseed (8g/100g), chia seed (8g/100g), Amaranthus Dubius (1.4g/100g) and carrot powder (2.8g/100g) were found to be the appropriate amounts of components by methodical research; this produced a moisture content of 3.403 and a water activity of 0.650. In this scenario, improving the nutritional profile and stability of the product, this study demonstrates how responsive surface approach may be used to optimise component levels and achieve desired product features.

Darniadi et al. (2012) focused on snack bars made with composite flour in order to address the crucial problem of preventing famine in post-disaster situations by providing Emergency Food Products (EFPs). The study used RSM to optimise the recipe for composite flour-based snack bars for EFPs. Fructose, margarine, egg yolk, full cream milk powder (FMP), maltodextrin, fruit jam and dried fruit were among the important independent factors that were taken into account. The answers included textural qualities, chemical properties, water activity (aw) and colour. Based on the greatest appeal rating, the optimised composite flour formula consisted of 50.5 percent sweet potato, 37.5 percent mung beans and 12.5 percent soybeans. The resultant snack bars had a total caloric content of 418.43 kcal and balanced amounts of fat, protein, carbs and fiber. The product also satisfied EFP requirements for manganese, vitamin K and other critical vitamins and minerals. This study emphasises how important it is to use RSM to create standardised, nutrient dense EFPs that efficiently meet the critical nutritional demands of catastrophe victims.

While there is a wealth of research utilizing optimization techniques like RSM to analyze various parameters such as textural qualities, chemical properties, microbial properties, shelf stability and cost-effectiveness in the production of food bars, there appears to be a scarcity of studies focusing on the sensory attributes and acceptability of such bars at the consumer level. Sensory evaluation plays a crucial role in determining consumer acceptance and preferences for food products, including bars. Understanding the sensory aspects of food bars, such as taste, aroma, appearance and

texture, is essential for ensuring consumer satisfaction and market success. Further research in this area could provide valuable insights into formulating food bars that not only meet nutritional requirements but also appeal to consumers' sensory preferences, thereby enhancing their overall acceptability and consumption. Such studies would contribute significantly to the development of innovative and consumer-friendly food bar products.

2.14 Characteristics of Protein Bars

Characterizing food bars entails conducting a thorough analysis of multiple attributes to gain insights into their composition, quality and suitability for consumption. Essential components of this characterization process include sensory analysis, nutritional composition evaluation, textural analysis, shelf stability assessment and cost analysis. By delving into these key aspects, researchers and food manufacturers can better understand the overall characteristics of food bars, facilitating product development, optimization and consumer acceptance.

Sensory Analysis

The assessment of sensory attributes, such as colour, mouthfeel, taste, body and texture, odour, flavour and aroma, as well as general acceptability, are crucial factors in determining the quality of food. Delivering enjoyment through the senses is essential to economic success and different meals and processed food items stimulate different sensory experiences. For the purpose of creating and promoting food goods, it is crucial to quantify, comprehend and enhance customers' sensory experiences. In order to effectively describe the qualitative attributes of meals and their products, the science of sensory assessment necessitates a proper comprehension of various sensory methodologies, as well as their application to address sensory queries and sensory parameters (Ray, 2021).

There are two approaches to evaluating sensory qualities of food products: objective or quantitative methods and subjective or qualitative ones. Organoleptic reactions to food characteristics are the subject of subjective sensory attribute evaluation, which is often accomplished by using a hedonic rating test and composite rating scale with trained panellists in an active role. Regular quality control requires an objective or discriminative analysis and testing typically requires the use of instruments or

equipment (Ray, 2021). Meilgaard et al. (1999) define sensory assessment as the process of evaluating the qualities perceivable by the five senses (colour, odour, taste, touch, texture and noise) in order to determine the overall quality of a product. According to Srilakshmi (2010), although these characteristics are present in the meal itself, people's responses to them are impacted by a variety of psychological and social variables. This subjectivity emphasises how crucial sensory assessment is in figuring out customer acceptability and preference. Furthermore, Manay (2001) points out a number of uses for sensory assessment, such as upholding standards for food quality, evaluating differences in processes, cutting expenses, improving the quality of products, investigating new markets and doing market research. Sensory analysis finds applications across diverse domains, including product development, product enhancement, quality assurance, storage investigations and process refinement (Watts et al., 1989).

To provide trustworthy and valid data, a sensory panel should be treated as a scientific instrument, with controlled settings, suitable experimental designs, test techniques and statistical analysis. Watts et al. (1989) emphasise the need of conducting sensory testing under controlled settings in order to ensure data consistency and repeatability. Researchers can get accurate insights into customer perceptions and preferences for food and other consumer items by approaching sensory assessment as a scientific endeavour and applying rigorous procedures.

Four forms of sensory testing are commonly employed, each with a distinct aim and participants chosen using different criteria. These testing procedures are (i) Difference or discrimination testing (paired comparison test, triangle test and duo-trio test); (ii) Rating tests (ranking test, single sample test, two-sample difference test, multiple-sample difference test, hedonic rating test, numerical scoring test and composite scoring test and (iii) Sensitivity test (Sensitive-threshold test and dilution test) (iv) Descriptive flavour profile testing (Srilakshmi, 2010). Composite Score Card (CSC) method and Nine- Point Hedonic scales are commonly used in studies related to new food product development.

Samakradhamrongthai et al. (2021) assessed the sensory characteristics of high energy cereal bars (HCB), revealing a range of sensory rating scores on a 9-Point Hedonic Scale. Participants rated various attributes of the HCB, including appearance (6.8–7.4),

Review of Literature

color (6.8–7.4), aroma (6.5–7.3), flavor (6.3–7.4), texture (4.7–6.9), stickiness (5.5–6.7), aftertaste (6.0–6.6) and overall liking (5.0–7.1). These findings suggest that the combination of cereals, fruits and sweeteners in the cereal bar formulation significantly influenced the preference rating scores of HCB. Such sensory evaluation results provide valuable insights into consumer perceptions and preferences, informing further product development and optimization strategies.

Srebernick et al. (2016) conducted evaluations with 50 consumers of cereal bars, utilizing a 9-point hedonic scale to assess the acceptability of appearance and overall product likability. Participants rated attributes such as color, texture (adhesiveness, crunchiness, chewiness), flavor (caramel, fruit) and taste (sweetness, acidity) for intensity on a scale ranging from 1 (very little intense) to 9 (extremely intense). Additionally, purchase intent was gauged using a 5-point scale, with options ranging from definitely buy to definitely would not buy. The study involved volunteer consumers who were selected by invitation and provided written consent, ensuring ethical standards were upheld in the research process. These comprehensive evaluations provide valuable insights into consumer perceptions and preferences, aiding in the refinement and development of cereal bar products.

Chapman et al. (2001) and Helland et al. (2016) employed Quantitative Descriptive Sensory Analysis (QDA) in their respective studies. This approach involves training panellists to assess specific attributes of a product consistently, yielding a quantitative product description suitable for statistical analysis. Johnson et al. (2003) evaluated the sensory acceptability of white bread using a 15 cm descriptive anchored line scale, with anchors ranging from highly unacceptable to highly acceptable for overall acceptability. Results indicated that the overall acceptability of white bread varied between 9.29 to 10.28. Manickavasagan et al. (2016) introduced a new sensory scoring system termed 'net acceptance score', derived from values obtained in a nine-point hedonic scale (9-PHS), to evaluate the acceptability of Omani grain products (*samoon, khubs and rekhal*).

A nine-point hedonic scale was utilised by researchers in their studies to evaluate the sensory attributes of recently created food products. Table 2.14.1 gives a summary of studies utilizing 9-Point Hedonic Scale for sensory evaluation of food products.

Table 2.14.1 Studies Utilizing 9-Point Hedonic Scale for Sensory Evaluation of Food Products

Food Product	Researchers	Main Findings
Tikki, Pancake	Kaur et al. (2016)	Assessed sensory qualities of tikki and pancake
Functional Beverages	Ogundele et al. (2016)	Evaluated sensory attributes of functional beverages
Bread	Wang et al. (2002)	Examined sensory qualities of bread
Flour Blends (Soyflour: Papaya Pulp Flour)	Ukwuru and Adama (2003)	Investigated sensory attributes of flour blends
Baked Products	Baixauli et al. (2008a)	Assessed sensory qualities of various baked products
Muffins	Baixauli et al. (2008b)	Evaluated sensory attributes of muffins
Reduced Calorie Biscuits	Aggarwal et al. (2016)	Examined sensory qualities of reduced calorie biscuits

Source: Gupta, (2016)

Composite scoring is a widely used method across various industries, particularly in product evaluation and quality assessment processes. This approach entails separately evaluating individual attributes or characteristics of a product and then combining these scores to provide an overall assessment of the product's acceptability or quality. In the context of food product evaluation, composite scoring may involve assessing attributes such as color, texture, flavor, aroma and freshness. Each attribute is typically assigned a score based on predefined criteria or scales, which can be numerical, categorical, or qualitative, depending on the specific evaluation method employed. Despite its widespread application, there is currently no available study that utilizes a composite scorecard to evaluate the sensory attributes of food bars. This presents an opportunity for future research to explore the efficacy and applicability of composite scoring in assessing the sensory qualities of food bars, potentially enhancing the understanding of consumer preferences and product quality in this domain.

Nutrient Composition

Protein is the principal element of protein nutrition bars, with a high amount of protein in comparison to carbs and lipids. While there is no official guideline, such bars often include 15–45% protein by weight (Lu and Zhou, 2019). According to rules set by the Food Safety and Standards Authority of India (FSSAI) in 2016, protein nutrition bars designed as meal replacement products should include no less than 25% and no more than 50% of total calories from protein (Ayatti, 2021).

Faria et al. (2018) conducted a proximate analysis of a novel soybean-based high protein bar developed by substituting whey protein with isolated soy protein (ISP). Their findings revealed that protein bars formulated with 75 percent ISP had the lowest carbohydrate content at 9.11 percent, along with high protein content at 37.42 percent and high fiber content at 26 percent. Additionally, these bars exhibited a low calorific value of 117.63 kilocalories per 30-gram portion. The study concluded that incorporating ISP into protein bar formulations enhanced their nutritional profile, resulting in bars with elevated protein and fiber contents and reduced simple sugar content. As a result, these protein bars were deemed suitable for inclusion in the diets of individuals with diabetes as well as healthy individuals.

Defatted sesame flour was used by Abbas et al. (2016) to create high protein and energy snack bars. The bars that were supplemented with 50% defatted sesame flour showed the greatest overall quality, with 4.5 percent moisture content, 35.73 percent crude protein and 0.61 percent crude fat, according to the results of the proximate analysis. They also offered 361 kilocalories (kCal) of energy per serving, 2.14 percent crude fibre and 2.44 percent total ash. 486.75 mg of potassium, 38.20 mg of sodium, 7.90 mg of iron and 52.86 mg of calcium were present per 100 g of these bars. The authors suggested that school nutrition programmes use these bars with added sesame.

Use of defatted sesame flour allowed Abbas et al. (2016) to create high-protein, high-energy meal bars. With 4.5 percent moisture content, 35.73 percent crude protein and 0.61 percent crude fat, bars supplemented with 50 percent defatted sesame flour showed the best quality, according to the findings of the approximate analysis. Besides that, they have 2.14 percent crude fibre, 2.44 percent total ash and 361 kilocalories of energy. Each 100 g of these bars included the following mineral contents: 486.75 mg of potassium, 38.20 mg of sodium, 7.90 mg of iron and 52.86 mg of calcium. The inclusion of these bars enriched with sesame in school nutrition programmes was suggested by the authors.

Review of Literature

In 2012, Padmashree et al. created a composite cereal bar that was high in protein and had noteworthy nutritional qualities. The created bar has the following percentages: 7.2% moisture, 18.8% total protein, 24.3 % fat, 30.6 % sugar, 1.7 % total ash, 0.46 % crude fibre and 16.9% carbohydrate (by difference). For every 100 g, each cereal bar had 484 kilocalories of energy. The study shown that mixing soy isolates and concentrates with cereals including wheat, maize and barley might result in a nutrient-dense bar.

A nutri bar made of quinoa was introduced by Padmashree et al. (2018). Its nutritional analysis revealed important features. The bars had a calorific value of 426.75 kilocalories per 100 g and the following nutritional values: 7.33 percent moisture, 14.43 percent protein, 14.93 percent fat, 1.48 percent total ash, 3.14 percent crude fibre and 61.85 percent carbohydrates. The study found that adding quinoa might improve the protein quality and establish a good amino acid balance in a very nutritious bar, especially with greater amounts of lysine (5.1% to 6%) and methionine (0.4% to 1.0%).

In order to create baked energy bars, Rawat and Darappa (2015) substituted component mixes high in protein and fibre for brown flour. Brown flour, fiber-rich component mixture and protein-rich ingredient mixture comprised 9.1%, 6.1% and 2.6% moisture, respectively, according to the proximate composition analysis of the bars. They also showed the following compositions: 1.2%, 2.8% and 5.4% for ash; 12.6%, 6.5% and 49.0% for protein; 2.2%, 1.2% and 1.7% for fat; and 1.2%, 35.8% and 7.9% for dietary fibre. In contrast, the component mixture rich in fibre showed lower levels of fat and protein but greater levels of dietary fibre and minerals than brown flour, whereas the ingredient mixture rich in protein showed higher amounts of dietary fibre, ash and protein but lower levels of fat. According to the study's findings, adding 50% of a mixture of ingredients that were high in fibre and 50% of ingredients that were high in protein increased the amount of fibre and protein content by around 9 and 2 times, respectively.

Singh et al. (2020) developed nutrition bars based on chia seeds, incorporating varying concentrations of chia seed flour into the formulations. Their findings regarding the nutritional composition of these bars indicated a decrease in moisture content as chia seeds were incorporated, attributed to the inherently low moisture content of chia seeds. Concurrently, there was a progressive increase in protein (from 2.93% to 5.06%), fat

(from 2.0% to 4.5%), crude fiber (from 7.87% to 13.28%), ash (from 1.60% to 3.00%), carbohydrate content (from 49.34% to 52.94%) and energy values (from 227 to 272 kcal), corresponding to the higher quantities of these nutrients present in chia seeds. The study demonstrated the potential for utilizing dates and chia seeds in formulating chia-date bars, highlighting the nutritional significance of chia seeds, which are notably rich in polyunsaturated fatty acids (particularly linolenic acid at 68% and linoleic acid at 12–21%), protein (ranging from 15% to 25%) and fiber (ranging from 18% to 30%). Additionally, the study emphasized the high BV of proteins found in chia seeds, which accounts for approximately 19% of the total weight, underscoring their suitability for incorporation into functional food production.

2.15 Textural Properties

By methodically assessing their mechanical features, protein energy bars are subjected to Texture Profile Analysis (TPA), which sheds light on their textural attributes. Resilience, hardness, cohesiveness, springiness, gumminess and chewiness are typical criteria included in this examination. When a bar is cohesive, it evaluates how well it keeps together after deformation, whereas hardness relates to the force needed to compress the bar. Gummy bar refers to the amount of energy required to chew through it, while springiness shows how quickly the bar recovers to its former shape following compression.

Hogenkamp et al. (2011) state that texture is a significant influence in determining how consumers perceive a product and whether or not they would repurchase it. The protein content that is used in the formulation of protein bars has a direct correlation with the hardness level that is seen in them. A bar with an inadequate protein content may become pliable and mushy to the touch. On the other hand, as De la Fuente et al. (2002) point out, over-incorporating protein might result in a crumbly and brittle structure. It is noteworthy to mention that these attributes may differ based on the particular kind of protein used in the recipe.

Several studies have concentrated on the firmness of protein bars, often assessed through instrumental texture analysis, specifically measuring peak force. However, to comprehensively evaluate overall bar texture, another critical dimension, crumbliness/cohesiveness, must also be considered. In a study centered on three functionally modified dairy proteins, including a whey protein concentrate and two

milk protein concentrates, a mixture design approach was adopted to examine the combined effects of these proteins on bar texture. Instrumental texture parameters that aligned with sensory texture attributes were developed. Peak force (referred to as Force 1) was found to correlate with firmness (which is the opposite of softness), while maximum negative force (termed as Force 2) was associated with cohesiveness (opposite of crumbliness). Mathematical models with R^2 values exceeding 90% were formulated to optimize texture over a 12-month storage period, maintaining storage at 20°C, for bars utilizing one or more of the three proteins (Imtiaz et al., 2012).

Using texture measuring tools, the softness/firmness dimension in connection to bar hardening has been thoroughly studied (Li et al., 2008; Zhou et al., 2008a; Liu et al., 2009; Loveday et al., 2009; McMahon et al., 2009). Briefly discussing crumbliness/cohesiveness, Li et al. (2008) called it "bar integrity," emphasizing its importance in bar processing. With a major focus on bar hardening, they observed that the addition of milk protein isolate to bars can reduce "bar integrity," which in their study showed crumbliness. Apart from this, though, crumbliness and cohesiveness in bars have not yet been properly investigated. To have a more thorough grasp of bar texture, crumbliness/cohesiveness and softness/firmness must be measured instrumentally.

Multi-textured bars are the goal of bar makers. For this reason, it is crucial to comprehend how various proteins and protein combinations impact the two main dimensions of bar texture. Equating or forecasting the bar texture is now possible with this knowledge. It would be especially beneficial for ingredient suppliers and bar producers to establish a workable mechanism for accomplishing this goal instead of depending solely on trial-and-error methods. Short-term storage—three months or less—has usually been the focus of earlier research on bar systems. However, doing research under these settings might offer useful insights to the business, as the usual intended shelf life of a bar in the market is 12 months at ambient temperature (Imtiaz et al.).

Hardness measurements were conducted by Hogan et al., (2012) using a TA-HDi texture analyzer with a 5 kg load cell and a puncture test employing a cylindrical, 5 mm diameter probe at a penetration speed of 1 mm/s to a depth of 35% of the sample thickness. Samples were equilibrated to room temperature before testing. Data were

collected at a rate of 50 points/s and a 2 kg weight was used for load cell calibration. Measurements were taken at least 1 mm away from the sample edge to minimize wall effects. Six measurements were taken per bar per day, initially on freshly produced bars and intermittently after storage at 37°C. Hardness was expressed as peak force values (N) using Texture Expert Exceed Version 2.64 software.

Differences in hardness observed in bars containing WPI were primarily attributed to variations in water activity (a_w) between powder and liquid phases. Lowering a_w improved bar stability, but moisture migration did not explain textural differences between bars with different protein types. Pre-equilibration of sodium cyanide (NaCN) and WPI powders minimized a_w differences (0.707 and 0.702, respectively) and enhanced bar stability, though their relative tendencies to harden remained unchanged (Hogan et al., 2012).

2.16 Shelf-Life of Protein Bars

A food's shelf life is the amount duration during which it keeps its organoleptic quality intact, depending on a number of variables including formulation, processing, packaging and logistics of distribution. Distribution shelf life is contingent upon packaging and ambient factors (Bili and Taoukis, 1998). Food degradation rates, acceleration magnitudes and real shelf life under normal conditions may all be estimated by exposing it to controlled situations where one or more external influences are enhanced (Gordon, 1993). The industry frequently uses accelerated testing methods to gather crucial experimental data more quickly when storage times are long (Mizrahi, 2000).

In the study conducted by Sharifah et al. (2010), the shelf life of pineapple granola bars was investigated under both normal and accelerated storage conditions. The packaging materials used were oriented polypropylene and vapor metallized cast polypropylene of 55 μ thickness. The study found that under normal storage conditions (28°C, 70-80% relative humidity), the estimated shelf life of the product was 8.7 months, determined from accelerated storage data using an empirical formula. However, sensory evaluation results from the accelerated storage samples indicated acceptance only up to three months of storage. This suggests that while the accelerated storage method provided useful insights, the sensory evaluation provided a more accurate assessment of shelf

Review of Literature

life. The study also noted that the moisture content and free fatty acid levels were higher in accelerated storage samples compared to normal storage samples for the same duration. This suggests that accelerated storage conditions may lead to accelerated deterioration of the product. Overall, the study provides valuable insights into the shelf life of pineapple granola bars and highlights the importance of considering both accelerated storage data and sensory evaluation results in determining shelf life.

In the study by Jetavat et al. (2020), the sensory and physico-chemical changes in milk solids and cereal-based energy bars were examined during storage in metallized PET Polyester/Polyfilm pouches at cabinet temperature ($15 \pm 2^\circ\text{C}$). The findings indicated a decline in sensory scores and fracturability, alongside an increase in peroxide value, free fatty acids, water activity and hardness throughout the storage period. Additionally, the standard plate count increased, while coliform count and yeast and mold count remained absent until 150 days of storage. However, despite efforts to maintain quality, the overall acceptability score of the milk solids-based energy bar fell below 6.0 by the 150th day of storage. Consequently, the study concluded that the milk protein concentrate-based energy bar remained acceptable for consumption up to 135 days of storage at $15 \pm 2^\circ\text{C}$. This research provides valuable insights into the deterioration mechanisms of cereal-based energy bars during prolonged storage and underscores the importance of monitoring both sensory attributes and physico-chemical parameters to determine product acceptability over time.

In their 2020 study, Keefer et al. devised high-protein, low-carbohydrate bars using various sweeteners (sucralose, sucrose, monk fruit, stevia and fructose) sourced from pea protein (PP), MP and WPI. These bars underwent accelerated shelf-life testing at 35°C and 55% humidity for 35 days. Results indicated hardening in all bars regardless of protein type or sweetener source. Initially, WPI bars were the hardest but hardened at a slower pace, eventually equalizing. Conversely, PP and MP bars, while less dense initially, became drier and crumbly over time, with the fastest rate of breakdown. Bars with fructose were consistently harder and denser initially, with WPI-fructose bars being the hardest up to day fourteen. The study concluded that fructose's hygroscopic nature led to significant interactions with protein sources, impacting hardness after day fourteen and potentially mitigating bar hardening by aiding moisture migration.

In a study, Sharifah et al. (2010) examined the shelf life of pineapple granola bars, highlighting their role as a quick and nutritious breakfast option or snack. These bars, rich in vitamins and minerals, are particularly beneficial for weight control, meal replacement and boosting stamina and endurance in athletes. The study aimed to determine the shelf life of pineapple granola bars using accelerated methods, assessing both chemical and microbiological changes as well as organoleptic acceptability during storage. Through empirical calculations, the researchers found that one month of storage under accelerated conditions equated to 2.9 months under laboratory storage conditions. Notably, despite accelerated storage conditions, the actual shelf life of the pineapple granola bars in laboratory conditions was found to be 8.7 months based on sensory evaluation results. However, it was noted that these bars remained acceptable for consumption for up to three months of storage.

2.17 Packaging and Labeling requirements of Sports Bars

Using a variety of packing materials, Padmashree et al. (2012) looked at the durability of composite cereal bars during storage. Polypropylene (PP), paper-aluminum foil-polyethylene (PFP) and metallized polyester (MP) containers were used in the investigation and the bars were exposed to ambient temperatures between 15 and 34°C and 37°C. They saw modest but noticeable increases in moisture content throughout a nine-month storage period, independent of the packing material. However, chemical changes in the composite cereal bars were notably least in samples packed under vacuum in MP, followed by MP, PFP and PP packed samples when stored at ambient temperature. Parameters such as peroxide value (PV), free fatty acids (FFA), thiobarbituric acid (TBA) and browning index showed variations across the storage period, with more pronounced changes observed at 37°C compared to ambient temperature. This research sheds light on the influence of packaging and storage conditions on the chemical stability of composite cereal bars, providing valuable insights for product preservation strategies.

Rawat and Darappa (2015) investigated the chemical characteristics of baked energy bars (BEB) by incorporating fiber-rich ingredient mixture (FRIM) and protein-rich ingredient mixture (PRIM), stored at room temperature for three months (30°C, 65–75% RH). The study revealed minimal changes in moisture content across all BEBs during storage. Lipid oxidation, assessed by peroxide value and free fatty acid value,

indicated slight variations, with peroxide value ranging from 4.9 to 7.85 meq O₂/kg fat and free fatty acid from 4.82 to 8.6% oleic acid. External characteristics such as crust color, surface, crumb color, texture and mouthfeel remained unchanged, reflected in overall quality scores. The BEBs with 50% FRIM and PRIM demonstrated chemical stability and maintained good sensory characteristics throughout the three-month storage period. This study underscores the potential of FRIM and PRIM in enhancing the stability and sensory attributes of BEBs over time.

Jabeen et al. (2020) observed a declining trend in a_w in protein bars containing dates, apricots, cheese and WPI over 45 days of storage. The presence of casein protein in cheese led to increased water-binding properties, lowering the a_w of the product. Initially, the hardness and firmness of PE-bars decreased until the 30th day, attributed to the moisture-retaining properties of dates and dried apricots. However, later in storage, firmness and hardness increased due to moisture migration, reducing cross-linkages between sugars and proteins. Microbiological analysis indicated a decrease in total plate count, possibly due to the hygroscopic behaviour of dates drawing water away from the product. Antioxidant activity initially decreased, followed by a sudden increase at the 15th and 30th day, likely influenced by enzymes present in dates. However, antioxidant activity reduced by the 45th day. Despite visual acceptance decreasing, sensory attributes of PE-bars remained consistent throughout storage. This study emphasizes the dynamic changes in physical, chemical and sensory properties of PE-bars during storage, offering insights into their stability and quality over time.

2.18 Consumption Patterns and Perceptions of Food Bars among Athletes and Trainers

Effective consumer testing involves the careful selection of a substantial random sample of individuals who accurately represent the target community of potential users, aiming to gather insights into their views or preferences. Unlike professional sensory panellists, consumer panellists are chosen based on their product usage rather than their sensory acuity. Typically, between 100 to 500 people are surveyed or interviewed for this type of testing, with the findings extrapolated to predict the attitudes of the broader target population, as emphasized by Watts et al. (1989). It is essential to select a group of panellists who closely resemble the target population of consumers who use the product, ensuring that the feedback obtained is relevant and applicable to the intended market audience. This approach facilitates more informed decision-making and aids in the development of effective product strategies (Watts et al., 1989).

Review of Literature

An acceptability trial was conducted to assess the consumer preference for legume-supplemented ready-to-eat cereal bars among 50 male and 50 female students aged between 15 and 30 years. Using a 9-point hedonic scale, participants evaluated five treatments and a control. Results indicated that Processed Soyabean Cereal Bar (PSCB) was favoured by the majority of females, followed by the control group. Conversely, Defatted Soyabean Cereal Bar (DSCB) garnered higher acceptance among males compared to other treatments. This trial provides valuable insights into gender-specific preferences for legume-supplemented cereal bars, highlighting the importance of considering demographic factors in product development and marketing strategies (Yadav and Bhatnagar, 2016).

An anonymous online survey conducted in German during a recent study headed by Reinhard and Galloway (2022) examined the variables impacting the choices and consumption behaviours of carbohydrates while training among cyclists, runners and triathletes. With predetermined answers and a Likert scale ranging from 1 to 5, the poll drew 1,081 endurance participants, 58.0% of whom were male and 68.6% of whom were between the ages of 18 and 39. The majority of participants (67.4%, $n = 729$) favoured a combination of conventional meals and commercial sports nutrition products, with the former being more convenient in some activity scenarios (61.3%, $n = 447$). The convenience of consumption during physical activity was appreciated by those who only chose commercial items (19.3%, $n = 209$), whereas those who stuck to common foods (13.2%, $n = 143$) were driven by the perceived wholesomeness and natural ingredients (84.6%, $n = 121$). At low-to-moderate intensities ($n = 1032$), sports drinks were shown to be the most preferred CHO source, with a significant difference between them and bananas (2.27 ± 1.14 vs. 2.56 ± 1.33 , $p < 0.001$). Sports beverages continued to be the most popular option at higher intensities ($n = 1,077$), with gels (2.79 ± 1.37) and energy bars (2.43 ± 1.28) coming in second and third, respectively. All commercial sports nutrition items were significantly more eaten (all, $p < 0.001$). Across all activity intensities combined, 95.1% of individuals' ingested carbs during training. It is noteworthy that whereas females tended to choose ordinary meals more (1.66 ± 0.47 vs. 1.54 ± 0.42 , $p < 0.001$), males liked commercial sports nutrition items more (2.35 ± 0.70 vs. 2.14 ± 0.79 , $p < 0.001$). The majority (67.6%, $n = 731$) relied on intuition when determining how much CHO to consume during training. These findings underscore a widespread inclination towards liquid forms of carbohydrate intake during training among endurance athletes, regardless of exercise intensities, providing valuable insights for sports nutrition strategies and research endeavours.

An online cross-sectional survey was conducted among non-athlete Australian adults' aged 18 to 65, encompassing closed-ended questions on sports food consumption patterns, exercise engagement and factors shaping consumption habits. Additionally, open-ended inquiries explored the motivations behind sports food consumption, perceptions of associated risks and encountered side effects. Descriptive statistics, including frequencies and percentages, characterized the sample, while ordinal logistic regression determined associations between variables. A multivariate model examined relationships between frequency categories of sports food consumption (dependent variable) and significant univariate associations. Statistical significance was established at $p < 0.05$. Thematic analysis in NVivo 14 was employed to analyze responses to open-ended questions. Findings revealed that females consumed sports foods more frequently, with 65% of participants using three or more product types. Interestingly, individuals consuming a wider array of sports food types were less likely to perceive associated risks or encounter side effects. Notably, protein intake emerged as a primary motivation for sports food consumption, while concerns predominantly revolved around digestion and stomach issues, with bloating being the main side effect reported. Despite acknowledging risks and experiencing side effects, non-athlete consumers displayed a notable propensity for ingesting various sports foods, particularly protein products. Consumption patterns appeared to be influenced by sociodemographic factors and packaging labels. The study advocates for stricter regulation concerning the enforcement of packaging label information and restrictions on media advertising to ensure safer and more informed consumption among non-athlete consumers (Chapple et al., 2024).

According to a qualitative study by Cherian et al., 2020 on coaches' perceptions of sustenance, appetite and nutrition among teenage Indian athletes, adolescence is a critical developmental stage during which harmful behaviours may be adopted and carried into adulthood. Adolescent athletes are more likely to have poor eating habits, which can result in eating disorders and other medical problems. Given the lack of multidisciplinary support staff in India, coaches play a pivotal role in monitoring the eating habits of adolescent athletes. Therefore, our study aimed to explore coaches' perceptions regarding the food, appetite and nutrition of adolescent athletes through In-depth Interviews (IDI). Out of 14 coaches at a state-sponsored residential sports centre, 10 participated in the IDIs. The interviews were conducted systematically, recorded,

Review of Literature

transcribed and manually coded using open and axial coding in the grounded theory approach to identify themes. Coaches emphasized the importance of nutrition for performance, highlighting the significance of consuming higher amounts of animal protein. While they recognized foods like sprouts, dry fruits, fruits and vegetables as healthy, they struggled to quantify their intake or understand their nutritional components. Protein was deemed important, whereas fat was viewed as unhealthy. Coaches observed a tendency among athletes to avoid fruits and vegetables while increasing rice consumption. They also stressed the importance of meal timing, fluid intake and supplements for international performance, although they lacked awareness of specific requirements. Additionally, coaches noted that hygiene practices and peer isolation could impact food intake.

The impetus rationale behind the planning of this study stems from the recognized need for sports-specific convenience foods that not only meet nutritional requirements but also align with athletes' sensory preferences and practical considerations. Existing studies have highlighted the importance of taste, texture and overall acceptability in promoting adherence to nutritional regimens among athletes. However, there remains a paucity of research focused on systematically optimizing protein bar formulations to strike a balance between nutritional excellence and sensory appeal. By employing innovative approaches like RSM, this study aims to fill this gap by providing a structured framework to explore the synergistic effects of ingredients, concentrations and processing parameters on the final product. Ultimately, the goal is to develop Protein-Energy Bars that not only fulfil nutritional criteria but also meet consumer expectations in terms of taste, cost-effectiveness and shelf life, thereby enhancing compliance with dietary plans among individuals engaged in fitness activities.