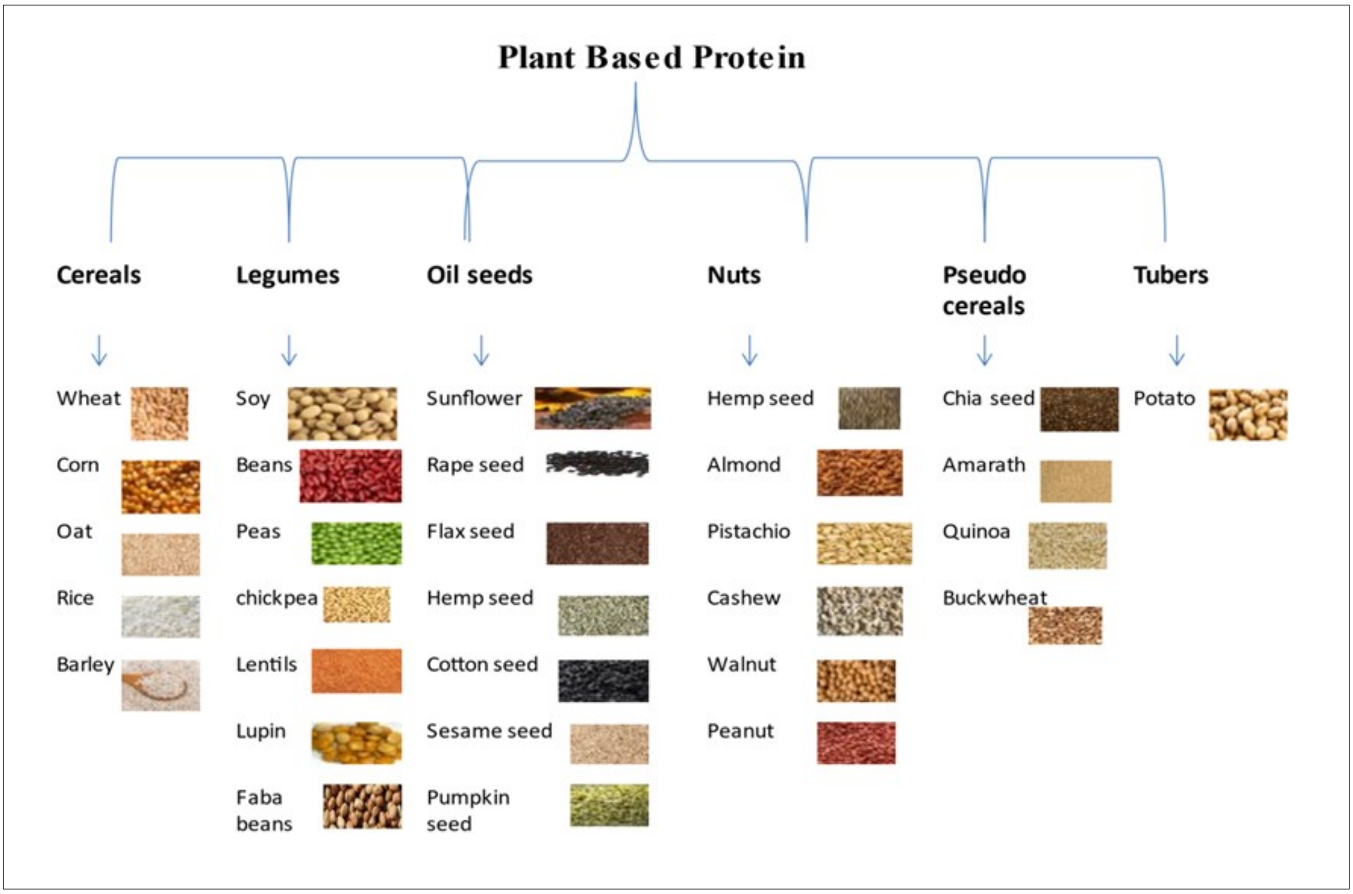

Fig. 1. The primary sources of proteins from plants.

Table 1. Structural and textural characteristics of plant protein sources in the development of meat analogue

Protein Source	Structural and Textural Characteristics	Reference
Peas	Water and fat binding, emulsification, and firm texture after thermal processing	(27)
Faba beans	Heat treatment and low-moisture extrusion cause a rise in water holding capacity, water solubility and gel strength, fibrous layered structure can be obtained with high-moisture extrusion	(28)
Chickpea	Low foaming capacity compared to soy, high foam stability, gelling ability similar to soy, and high water and oil binding capacity, which is beneficial for use in meat analogues, can also be used as colourants.	(29)
Peanuts	Arachin is the main protein that changes during extrusion, forming layered structures combined with other ingredients (e.g., carrageenan, gellan gum, transglutaminase), increasing gel strength, storage modulus and fracture stress.	(30, 31)
Mung beans	Albumins have better textural stability, texturization properties are temperature-dependent.	(32)
Soy	Good texturization properties, Good emulsification, gelling, and solubility	(33)
Wheat Gluten	Binding, low solubility, the formation of dough, cross-linking capacity via S–S-Sbridges	(34)
hemp seed meal	Good solubility, emulsification, water and oil holding capacity, least gelling concentration	(35)
Potato protein	Good emulsification, foaming and gelation properties make it a good texturizer.	(36)

Table 2. Advantages and disadvantages of different protein extraction methods

Extraction method	Advantages	Disadvantages	References
Conventional alkaline extraction (CAE)	High extraction yield (about 95% protein yield). • The easy extraction process, where don't need expensive machines. • Low cost. • Compatibility with downstream applications.	Long processing time. • The pollution of the environment is due to acidic and alkaline wastewater. • Poor solubility of protein concentrate and protein isolate when rehydrated. • Racemization and denaturation of extracted protein. • Formation of dehydro and cross-linked amino acids. • Low physicochemical, functional, and nutritional properties	(47, 48)
Subcritical and supercritical water	An environmentally friendly alternative to extracting protein with flammable organic solvents • Extraction/separation time is short. • High extraction yield. • It can be suitably scaled up for industrial applications. • The extracted protein showed high physicochemical, functional, and nutritional properties. • The high solubility of protein concentrate and protein isolate when rehydrated.	High pressure degrades the quaternary structure of proteins. • High pressure and temperature can collectively hydrolyze protein into small fragments and subsequently into free amino acids. • Proteins denatured through exposure to high pressure at room temperature. • Sub-supercritical water technology is a little bit expensive.	(49, 50)

Deep eutectic solvents (DESs) extraction	Biodegradability, sustainability, low volatility, low vapour pressure, low toxicity, non-flammability, and chemical tunability are the characteristics of DESs. • The high extraction efficiency of 70.2–93.95% under the optimal conditions. • The extracted proteins were non-denatured. • The high solubility of protein when rehydrated.	High viscosity hinders the dissolution of proteins and affects the solvent mass transfer phenomena, heat transfer rate, and conductivity. • Poor extraction selectivity and inefficient back-extraction method. • Some materials used to prepare DESs had mild cytotoxicity, such as ChCl-oxalic acid.	51,52,53,54
Reverse micelles (RMs) extraction	RMs are easy to implement. • Low cost due to the recovery of surfactant and nonpolar solvents. • Convenience and excellent potential in scaling up. • Proteins can be solubilized in the water pool of reverse micelles during the extraction. • Less protein denaturation and better functional properties. • A high ionic strength stripping solution can easily recover the denatured proteins without unfavourable interaction of ionic reverse micelles.	Higher water and energy consumption • Poor backward extraction efficiency • Loss of surfactant and proteins due to white colour insoluble complex forming on the two-phase interface • Low purity of the end protein product. • The most widely used system consists of sulfosuccinic acid bis (2-ethylhexyl) ester sodium salt and isooctane, which are not approved for food use.	(40)
Enzymatic-assisted extraction (EAE)	EAE increased the extraction yield and protein content by 2.2 –12% compared to CAE alone. • Reduced solvent usage with lower energy consumption. • Nontoxic treatment to increase extraction efficiency. • EAE is an environmentally friendly green processing technique. • Faster extraction with a high extraction rate. • Amenable to scale up	The enzymes used in the extraction process are costly. • Requires an optimization process to minimize enzyme dosage to achieve a high recovery yield. • When an enzyme is inactivated or separated, it can need an additional step. • Variations in enzyme activity between batches may have specific adverse effects.	(38)(55)
Ultrasound-assisted extraction (UAE)	UAE has been shown to reduce processing times and lower costs. • Low environmental burden. • Less protein denaturation due to the low operating temperature and temperature rise. • UAE increased protein extraction yield (86.1–91.2%). • UAE improved protein isolate and concentrate's physical, chemical, functional, and nutritional modifications. • High solubility, foam capacity, and foam stability of the extracted protein. • High water and oil holding capacity. • High product purity	High energy consumption. • Consumption of toxic organic solvents in the extract. • Denaturation of proteins at higher pH. • High capital investment. • High rejection of CO2. • UAE can only be used in pilot scales up to date. • Ultrasound-induced radicals can oxidize protein, affecting the structure and functions of the protein. • Long-time use of the probe can lead to erosion of the metal tip into the protein solution; thus, a metal part can be present in the protein solution	(39, 55, 56)
Microwave-assisted extraction (MAE)	Ease of use. • Low solvent volume. • High protein solubility. • High protein digestibility. • Higher rate of extraction, where MAE enhanced the protein extraction yield by 33.18% compared to CAE alone. • Higher-quality products. • Lower CO2 emissions compared to Soxhlet or solvent extraction with stirring. • High potential for scale-up.	Expensive equipment. • Dielectric properties of the solid material to absorb microwaves. • Microwave-induced radicals can oxidize protein, affecting the structure and functions of the protein. • Dielectric properties of the solid material to absorb microwaves. • Higher extraction time because it needs a clean-up step and waiting time for the extraction vessels to cool down.	(42, 55, 56)
High-pressure assisted extraction (HPAE)	Environmental friendly. • Nontoxic treatment. • Enhances the mass transfer process. • Increases extraction efficiency. • Reduces extraction time and decreases solvent consumption. • HP improved the protein's functional, structural, rheological and antioxidant properties. • HPA treatment increased protein solubility, water, and oil holding capacity. • Low thermal degradation • Microorganisms' inactivation. • Applicable on an industrial scale.	High equipment cost. • Complexity. • High energy consumption. • Formation of unwanted by-products. • This extraction approach can result in the deprotonation of charged groups and the breakdown of salt bridges and hydrophobic interactions, leading to protein structural alterations and denaturation.	(57, 44)
Pulse electric field -assisted extraction (PEF)	An environmentally friendly alternative to extracting protein with flammable organic solvents. • Energy consumption is low. • PEF is applied for a very short time (10−4 and 10−2 s) thus there is little heating effect on the sample (ΔT	Reversibility of the membrane changes. • The method's efficiency depends on electric field strength and electrode gap. • The existence of bubbles during treatment could result in operational problems and non-uniform treatment. • High cost of the equipment, which implies a high initial investment. • Commercial PEF units are not widely available in many regions worldwide.	(43, 58, 59)

Table 3: Production technologies of meat analogues

Protein source	Processing technology	Reference
Rice protein, WG	High moisture extrusion	(109)
Peanut protein	High moisture extrusion	(105)
Mung bean	High moisture extrusion	(110)
Faba bean: oat 80:20	Low moisture extrusion	(17)
Pea protein isolate (PPI) + wheat gluten	Shear cell technology	(111)
Pea protein isolate dispersions (10–21% w/w)	Three-dimensional extrusion printing, nozzle diameter of 1.6 mm, room temperature	(112)
Zein protein	Electrospinning	(113)
Soybean protein isolate (SPI) and sodium alginate (SA)	Wet spinning	(114)
Soybean protein isolate (SPI) and sodium alginate (SA)	Freeze-thawing	(115)
Single cell protein (SCP) and hydrocolloids	3D printing	(116)