

REVIEW ARTICLE

Food Innovation: Fungi and Vegetables Potential as A Healthy and Sustainable Meat Substitute

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ABSTRACT

One of the factor-driven global environmental concerns and health issues is excessive meat production and consumption. The popularity of meat substitutes for the benefit of sustainability and well-being has been increasing. This review highlights the health benefits, sustainability, and sensorial properties of plant-based materials as meat substitutes. Each of the materials has its advantages and disadvantages. Mushrooms, mycoprotein, soy, TVP, and seitan have a high potential to become a healthier and more sustainable meat alternative. However, there are some challenges, such as mushrooms' wide variety, mycoprotein production cost, beany and grainy nodes of soy-based products, increased seitan production that negatively impacts the environment, and low protein content of jackfruit. Nuts, cauliflower, potato, and eggplant require significant sensory improvement to mimic meat characteristics despite their environmental advantages. Moreover, their protein content and quality are low. On the other hand, Cottonseed proteins contain toxic gossypol, and research on their sustainability and nutritional value is limited. For legumes and lentils, their processing reduces some nutritional components and their taste and texture from meat. Overall, these fungi and vegetables possess great potential as meat substitutes due to their high nutritive value, workable sensorial properties, and good sustainability compared to conventional meat despite having their challenges to become potential plant-based meat products.

Keywords: meat substitutes; fungi; vegetables; nutritional value; sustainability

INTRODUCTION

Meat has been an essential component of the human diet for centuries as it has high protein content and quality. However, excessive meat consumption has become one of the major global environmental concerns due to its contribution to greenhouse gas emissions, pollution, increased land and water use, and biodiversity loss. This fact is proven by the more significant water waste (100 times more than

crop production) and three primary greenhouse gasses emissions (N₂O (65%), CH₄ (39%), and CO₂ (9%)) in meat production (Van der Weele *et al.*, 2019). The consumption of meat is also responsible for public health issues, such as colorectal cancer, cardiovascular disease, ischemic heart disease, and many other non-communicable diseases (Kumar *et al.*, 2015). One alternative to satisfy humans' craving for meat while tackling health and environmental

concerns is the idea of meat substitutes. The shift to plant-based meat is currently trending for various reasons, e.g., unique nutritional value, sustainability (lower cost, more social profits, less environmental impacts), and personal beliefs (Ergun *et al.*, 2016). Though the shift to plant-based meats is promoted alongside social matters, the potential meat alternatives should own the same functionalities as traditional meats to mimic meat texture, which primarily consists of the ability to create stable gels/emulsions and have a strong water holding capacity (Kyriakopoulou *et al.*, 2021).

Some examples of meat alternatives include legumes, pulses, mushrooms, mycoprotein, algae, soy-based products, vegetable protein, jackfruit, and many more. They are created to mimic the fibrous texture, appearance, and flavor of meat yet being more cost-effective, sustainable, and healthier (i.e., lowering non-communicable disease risks). Instead of providing high levels of unhealthy fats and sodium, plant-based meat has higher levels and varieties of vitamins (A, B vitamins, E, C), minerals (e.g., Ca, Fe, Mg, Zn, Se), dietary fibers, protein (essential amino acids), and antioxidants (Tuso, 2013; van der Weele *et al.*, 2019). The concept of meat alternatives is not intended to change the whole product idea; instead, to replace the conventional meat through healthier, more sustainable, and innovative plant-based substitutes that exert similar sensorial properties and health benefits as meat, such as 'chicken' nuggets made from pea protein or jackfruit, burger patties made from legumes or seitan, and tofu with tempeh as one of the most well-known soy-based meat replacers (Siegrist & Hartmann, 2019; Kyriakopoulou *et al.*, 2019).

Therefore, this review aims to raise awareness of fungi (mushroom and mycoprotein), vegetables (legumes, pulses, nuts,

jackfruit, eggplant, cauliflower, potato), and their derivatives as a healthy, sustainable, and innovative meat substitute by laying out their potentials in terms of nutritional value (health benefits), sensorial properties (customer acceptance), and sustainability (environmental impacts, social and economic profits). This article also covers more insights regarding some uncommon vegetables that have not been mentioned in other reviews before.

FUNGI

Mushroom

Mushroom is a popular food source, especially for its stipe that is utilized in the formulation of muscle food products such as salted cooked beef, braised beef or pulled pork, beef taco, kuruma shrimp, chicken sausages, and tuna meat, due to its fibrous structure that mimics the texture of meat analogs and provides a unique taste and umami flavor (Sirimuangmoon *et al.*, 2016; Lang, 2020; Das *et al.*, 2021). Its familiarity and compatibility with meat ease consumer acceptance compared to other plant-based ingredients (protein derivatives/artificial vegetables, lentils, and soy). The umami flavor derives from 5'-ribonucleotides, glutamic, and aspartic acid, a natural form of the flavor enhancer monosodium glutamate (MSG) that owns a small amount of sodium (5 mg/100 g raw white). Due to its natural flavor-enhancing properties, 80% substitution of meat with mushroom is shown to reduce 25% of sodium content in the final product, making it a healthier option (i.e., lower sodium and calorie levels) for managing the weight balance and as an alternative to hypertension patients, yet retaining the overall meat flavor (Myrdal Miller *et al.*, 2014; Sirimuangmoon *et al.*, 2016).

Mushrooms are a good source of antioxidants, several minerals, and vitamins (Table 2) (Feeney *et al.*, 2014; Patinho *et al.*, 2019). Additionally, the PDCAAS (Protein Digestibility Corrected Amino Acid Score) values of *Agaricus bisporus* mushroom range from 0.35 to 0.70 with the protein content varying from 28.6 - 58.1%, and it does not contain lysine, tryptophan, cysteine, and methionine (Table 3). Hence, mushrooms have a lower protein quality than the meat and dairy group (González *et al.*, 2020; Enas *et al.*, 2016).

Due to its wide variety, it is difficult to find the best type and proportion that resembles meat in texture and appearance (Feeney *et al.*, 2014). Cooking techniques significantly impact the sensory properties of mushroom-based meat. For example, the substitutions of 50% and 80% (w/w) mushrooms prepared by searing had similar overall moisture content and flavor (umami, veggy, earthy, sweet, and garlic) to 100% sauteed beef carne asada. However, searing reduced the firmness and chewy texture of the beef (Myrdal Miller *et al.*, 2014; Sirimuangmoon *et al.*, 2016). Despite that, most consumers preferred seared mushrooms due to meatier and more intense smoky notes (Myrdal Miller *et al.*, 2014).

Mushrooms play an essential role in biologically diverse and healthy ecosystems, owing to their ability to recycle nitrogen and carbon compounds (i.e., in the form of crops and byproducts). For instance, Patinho *et al.* (2019) mentioned that mushroom production utilizes agroindustrial byproducts such as cocoa husks, soybean hulls, cottonseed peels, and crushed corn cobs as their substrates to grow (Patinho *et al.*, 2019). As a result, mushroom farms have been shown to exert a lesser environmental carbon footprint compared to other farms (Wendiro *et al.*, 2019). According to Bringye *et al.* (2021), mushrooms emit 0.5 kg of CO₂ per

pound of food consumed, whereas chicken, eggs, and pork, emit 3.1, 2.2, and 5.5 kg CO₂ per pound consumed, respectively. Aside from that, mushrooms can be grown quickly and fast in small spaces and indoor areas, conserving soil and requiring less water and energy (Myrdal Miller *et al.*, 2014).

Mycoprotein

Mycoprotein is a unicellular protein derived from the filamentous fungus *Fusarium venenatum*. Its dry matter contains 45% protein, 25% fiber, 13% fat, 10% carbohydrate with a range of vitamins and minerals (Finnigan *et al.*, 2017). Its PDCAAS is close to 1.0, containing all essential amino acids (Table 3). Aside from its high fibrous meat-like texture and better quality protein than other plant-based protein sources, mycoprotein fibers also help to improve insulin sensitivity, glycemic profile, decrease insulin concentrations and total blood cholesterol and does not affect mineral absorption (Souza Filho *et al.*, 2019; Ajwalia, 2020; Finnigan *et al.*, 2017). Although, it may lead to gout as its RNA content (higher than beef liver) increases uric acid level (Asgar *et al.*, 2010). Fortunately, Matassa *et al.* (2016) and Souza Filho *et al.* (2019) explained that molding mycoprotein to represent meat flavor and texture was easy as they closely resemble it. Therefore, it has been commercialized into sausages and patties.

Souza Filho *et al.* (2019) stated that although the carbon emission generated by mycoprotein production is slightly higher than pork and chicken, it is a more efficient alternative in terms of land and water usage than meat production. It was also mentioned that the current production method, where the grown fungi are treated to reduce its RNA content and add egg albumen, color, and flavors to mimic meat, has a similar cost to meat. The authors also mentioned

that 45% of mycoprotein's overall environmental impact was sourced from its processing, 25% was for frying, and 21% was linked with the components in its production, such as egg white (10%) and nitrogen fertilizer (11%) to grow fungal-substrate-crops. Hence, the challenges to popularizing mycoprotein include reducing production costs and public awareness of its health and environmental benefits.

PULSES AND LEGUMES

Beans, Lentils, and Peas

Legumes (e.g., peanuts, fresh beans, and peas) and pulses (e.g., beans, lentils, chickpeas) are considered to be a great and affordable protein source (24.63%) for tropical and subtropical countries (Figueira *et al.*, 2019; Tiwari *et al.*, 2011; Hayes, 2018). Besides protein, legumes are rich in fiber (10.7%), vitamins, minerals (6.51 mg of iron and 35 mg of calcium per 100 gr), polyunsaturated and monounsaturated fatty acids (Table 2) (Rizzo & Baroni, 2018; Yadav, McNeil & Stevenson, 2007). Lentils and legumes have PDCAAS values ranging from 0.5-0.6, providing all essential amino acids, except methionine and cysteine (Table 3) (Erskine, 2009; Nosworthy *et al.*, 2017). Legumes are categorized as low-glycemic index food, which contributes to its wide range of beneficial health effects, such as reducing the risk of cardiovascular disease, cancer, diabetes and promoting weight loss due to its satiety-inducing feeling (Tiwari *et al.*, 2011). Unfortunately, lentils and legumes-based meat products usually have distinct taste and texture characteristics from real meat (neither juicy nor fatty, yet beany, grainy). However, due to their beneficial health effects and low price, legumes and pulses have been included globally in the 'Meat Alternatives'

group (Figueira *et al.*, 2019; Kaczmarska *et al.*, 2021).

A wide variety of legumes (e.g., black beans, kidney beans, chickpeas, black-eyed peas) cooperate well with other cuisines due to their subtle flavor, especially for the main ingredient of meat-free dishes, such as black bean burger, black-eyed pea Italian sausages, chickpea patty, and chickpea 'tuna' salad (Kaye, 2019; Polak *et al.*, 2015). Other than the neutral flavor, their high dietary fibers content contributes to excellent water/oil binding and swelling capabilities, which is advantageous for a great meat alternative and fat replacer in meat products (Maphosa & Jideani, 2017; "Legumes and Pulses," 2020).

Lentils have always been a potential ingredient for substituting meat from the early practice of veganism due to its affordability and hearty texture. All types of lentils (red, green, and brown) have promising nutritional value with different sensorial attributes of the final food: (1) red lentils having a subtler flavor with mushy texture development when cooked, perfect as a thickening agent; (2) green and brown ones having a slightly earthy flavor while holding their shape when cooked, ideal for replacing meat (Kaye, 2019). Generally, these main types of lentils are burgers, meatballs, tacos, and stew (McMeans, 2019; Purviance *et al.*, 2014).

Legumes are also considered relatively sustainable crops, generating significant positive effects on biodiversity and soil health by creating their nitrogen from the atmosphere and thus reducing nitrogen fertilizers application, which mitigates the emissions of greenhouse gases and is beneficial for the next crop in its place. Moreover, its cultivation allows carbon sequestration in soils, releasing up to seven times fewer greenhouse gasses per area than other crops (Meena *et al.*, 2018). Additionally,

FAO (2016) stated that pulses help to minimize food waste due to their long storage period without losing nutritional value.

Soy

Soy (*Glycine max L.*) is chosen as a meat protein replacement due to its high protein content (Table 2) and complete essential amino acids (Table 3) (Messina & Messina, 2010; Hassan, 2013; Mousavi *et al.*, 2019). Soybeans also include carbohydrates, oils, minerals, and vitamins (Table 2) (Hassan, 2013). Its consumption in diets comes with other health benefits: (1) reduce blood cholesterol and heart disease risks (Kumar, 2016), and (2) its bioactive compounds (isoflavonoid) help reduce risks of certain cancers (lung, breast, colon, and prostate) (Hassan, 2013). Soy is more environmentally friendly to be made into meat analogs as they exert less environmental impact than traditional meats by utilizing less land, water, and energy during processing (Kyriakopoulou *et al.*, 2019; Pimentel & Pimentel, 2003).

Soy can be made into other products, such as tofu and tempeh, both created through soybean fermentation with the mold *Rhizopus oligosporus*. The mold extends the mycelium to connect the individual soybeans, resulting in a 'cake-like structure (Xiao, 2011). Tofu and tempeh are commonly used as meat alternatives because the foods mimic traditional meat's structure and textural properties (Kyriakopoulou *et al.*, 2019; Ergun *et al.*, 2016). The nutritional values are relatively different from dry soybeans due to the processing. However, they are still considered a healthy meat alternative. Tofu provides Fe and Ca, while tempeh contains vitamin B12, rare in plant-based foods (Kumar, 2016).

In terms of proteins, Rizzo & Baroni (2018) have shown that soybeans have a high protein content and quality (Table 3). According to the same study, the protein content is about 36-46%, making it has the highest protein content amongst other legumes. It was also found that soy proteins have a PDCAAS of 0.92-1.00, implying high digestibility and good protein quality. The study claims that there might be minor variations in the PDCAAS in different soy-based products. This study is supported by the findings of Hughes *et al.* (2011), as their results showed that isolated soy proteins and soy protein concentrate (soy-based products) have a PDCAAS of 0.978-1.033 and 1.068, respectively. This characteristic in soy makes it advantageous for it to be an alternative to traditional meats.

Nevertheless, there are still some challenges that exist when incorporating soy as a meat alternative. Soy-based products have off-flavor-associated components, such as saponins and isoflavones (Asgar *et al.*, 2010). The undesirable off-flavors are often described as 'beany' or bitter (Lock, 2007). Additionally, soy-based products have a texture that does not resemble meat. Although, Osen & Schweiggert-Weisz (2016) mentioned that the moisture content should not be as low as moisture content is a crucial parameter to create desirable texture in the product.

Hence, some additional steps could be conducted to cover the undesirable sensory characteristics, such as the unpleasant taste with vegetable-based chicken or other meat flavors and genetic modification. Glycinin and β -conglycinin (significant components of soybean protein) can be modified to achieve the desirable physicochemical properties through modern genetic engineering, proving its potential as a great meat alternative product (Asgar *et al.*, 2010).

VEGETABLE PROTEIN

Textured Vegetable Proteins (TVP)

Textured vegetable proteins (TVP) are protein isolates made from plant-based sources that are often used as ingredients for meat analogs (Brishti *et al.*, 2017; Clayton *et al.*, 2019) and meat replacers (Riaz, 2011). TVP typically consists of soy protein or concentrate with other ingredients, such as emulsifiers and surfactants, to provide proper texture (Asgar *et al.*, 2010). TVP is made by passing soy flour through an extruder at varying temperatures to produce a fibrous product that can provide 'meat' like characteristics (Riaz, 2011; Branch & Maria, 2017).

The sensorial properties of TVP are generally accepted by panelists, where it gives desirable texture such as juiciness and mimics a similar taste to meat (Khurram *et al.*, 2003). Nevertheless, studies have shown that the desirability and palatability of TVP decrease as the level of soy increases. Besides, sensory properties depend on the processing method of meat analog. As an example, Wi *et al.* (2020) showed that the sensorial aspect of emulsified TVP is better accepted than TVP treated with oil. In addition, microwave cooking resulted in increased moisture loss and diminished beef flavor (Taylor *et al.*, 2012).

TVP application is considered a healthy and economically effective option (Asgar *et al.*, 2010). The nutritional value of TVP is similar to traditional meat products, except no cholesterol (1% fat) and low sodium level (Table 2), allowing TVP to be an ideal substitute for a range of meat-based products (Riaz, 2001). Besides having no cholesterol, TVP is rich in fiber (31%) and protein (51%). Hughes *et al.* (2011) mentioned that the PDCAAS published results of TVP may differ depending on the soy protein ingredient and the testing method's reproducibility and accuracy.

PDCAAS scores for soy protein concentrate are almost 1.0, making it a complete protein source (Table 3) containing all essential amino acids (i.e., same protein quality as meat, milk, and eggs). It also has numerous functional benefits, including treatment for malnutrition and reduced cancer risk (breast, colon, prostate) (Roberts, 2013).

Generally, TVP is made as meat analogs or extenders, where the former could be consumed as it is after rehydration, while the latter would be added into a processed meat product to reduce production costs (Asgar *et al.*, 2010). As TVP is supposed to act as a substitute that mimics meat products, the difficulty in developing the TVP is obtaining similar attributes to the conventional meat product (Ismail *et al.*, 2020). Meanwhile, its sustainability is considered similar to soy.

Seitan

For centuries, seitan has been widely produced and consumed as an old Japanese wheat product in East Asia. Seitan gives a chewy texture, similar to stringy fibers in meat texture, due to relatively high protein content (19%) that has 91% for its total amino acids (Table 3) standard ileal digestibility (SID) (Bogueva *et al.*, 2018; Dekkers *et al.*, 2018; Reynaud *et al.*, 2021). Additionally, seitan has low-fat levels with high vitamins and minerals levels (Table 2) (Bogueva *et al.*, 2019).

Its production requires the dissolution of wheat flour in water and subsequent kneading until a doughy elastic consistency. The dough is rinsed repeatedly, followed by second kneading and the addition of seasonings to convert its mild and neutral flavor to a meaty flavor. These result in the isolation of gluten (i.e., glutenin and gliadin protein) from the wheat (Schösler *et al.*, 2012; Bogueva *et al.*, 2018; Dekkers *et al.*, 2018).

Several seitan cuisines to replace meat include skewered deep-fried seitan in breaded batter, seitan burger, seitan pâté, sausage, and chicken (Shurtleff & Aoyagi, 2014; Bogueva *et al.*, 2019). Mal'a *et al.* (2010) replaced beef sausage partially with seitan-colored red yeast rice, and it received positive reviews from participants as it produced a unique taste and improved the consistency. Despite being ranked fourth among 13 food items tested for its attractiveness and consumer liking, gluten in seitan may not be suitable for gluten-intolerant people (Schösler *et al.*, 2012; Bogueva *et al.*, 2018; Dekkers *et al.*, 2018).

Berardy (2012) explained that seitan might not be the complete substitute for beef in terms of its flavor, versatility in cooking, and texture as it is usually used as wheat-based food. Although its production has a lower environmental impact than beef, it can reduce 50 points of environmental impact when seitan replaces 1000 servings.

Cottonseed Proteins

Cottonseed, found in tropical and temperate countries, is one of the richest oilseed sources processed into edible fat. Cottonseed proteins are commonly known as textured plant/vegetable proteins for meat analogs. It has high-protein content (23%), minerals, and vitamins (Table 2-3) with less price compared to soy concentrate (Ergun *et al.*, 2016; Shurtleff & Aoyagi, 2016; Ma *et al.*, 2018). Further studies to investigate the protein quality of cottonseed protein in terms of its digestibility based on the PDCAAS need to be done.

Many meat extenders are available in chunks, flaked, or minced forms commonly extruded from cottonseed protein products. According to a study from Molonon & Bowers (1976), the increasing amount of textured cottonseed flour

added to ground beef increased the cereal aroma and flavor yet decreased beef aroma and flavor. The addition of cottonseed protein increases the stability of the meat during storage due to its antioxidant properties. Moreover, cottonseed protein has a bland flavor, giving the beef a milder and softer texture (Molonon & Bowers, 1976). All of these are good attributes of cottonseed protein.

A moderate level of cottonseed protein (1 g/kg of body weight) with $\frac{1}{3}$ of it derived from LCP (liquid cyclone process) significantly increases children's height over six months (ARS, 1975). Furthermore, incorporating 38% cottonseed flour provides an excellent protein source for post-recovery treatment for kwashiorkor disease (Rathore *et al.*, 2020).

In 2008, the global yield of cottonseed was enough to satisfy the total protein requirements of 500 million people for a year (Ma *et al.*, 2018; Carmody *et al.*, 2019). Nevertheless, cottonseed is underutilized due to gossypol, a lipid-soluble phenolic compound produced by pigment glands in cotton flower buds, leaves, stems, and seeds (Keshmiri-Neghab & Goliaei, 2013; Gadelha, 2014). Cottonseed must contain less than 0.045% of free gossypol to be edible (Ma *et al.*, 2018). High free gossypol concentration results in gossypol poisoning, including anti-fertility, anorexia, interference with immune function, respiratory distress, weakness, impaired body weight gain, apathy, and even death after several days (Gadelha, 2014). These toxic effects can be avoided through 2 ounces/day of consumption limitation (Rathore *et al.*, 2020). Gossypol reduction is made by two-stage solvent extraction using aqueous and anhydrous acetone, while the complete elimination is through RNA interference (Asgar *et al.*, 2010). Due to the free gossypol, this can be seen as a limitation to the cottonseed protein. Moreover, its sustainability still needs further research.

NUTS

Nuts are defined as a fruit made of seeds enclosed in a hard outer shell. Its broad classification includes beech family (e.g., chestnut, chinquapin), birch family (e.g., hazelnut), cashew family (e.g., cashew, pistachio), legume family (e.g., peanut), pine family (e.g., pine), protea family (e.g., macadamia), sapucaia family (e.g., brazil nut, paradise nut), and walnut family (e.g., walnut). For thousands of years, nuts have been one of the essential parts of the human diet. They can be consumed raw, roasted, as an ingredient in specific dishes (sauces), or through food industries products (chocolate, almond milk) (Isabel C F R. *et al.*, 2017; Stoker, 2006; Tadayyon, 2013). Additionally, nuts have already been used for meat alternatives since 20-30 years ago; for example, nuts as the main ingredient for nut cutlet and minced-beef from nuts (Rehrah *et al.*, 2009; Sadler, 2004).

A hundred grams of nuts can provide 18.23 gr of proteins, 3.01 grams of fibers, and 11.6 gr of fats (Table 2) with a low amount of saturated fatty acids that take part in reducing the risk of cardiovascular heart disease (Fresan *et al.*, 2019). The ratio of SFA and UFA is highest for hazelnuts (11:9), pecans (10:9), walnuts (9:0), and almonds (9:0). Its plant sterols reduce cholesterol, while the fiber induces satiety and promotes weight loss. Besides vitamin E content that improves hair and nails quality, antioxidants, and minerals, it also has a high quality of proteins (PDCAAS ranging between 0.5 to 0.9), providing all essential amino acids (Table 3).

The inherent oily and crunchy texture from nuts makes the sensorial qualities quite different from real-meat sensory properties. Generally, nuts are combined with other additives to mimic the texture and flavor of real meat. Walnut and

almond are commonly used as base ingredients of plant-based meats, e.g., meatball and taco (Fiorentini *et al.*, 2020; Freitas *et al.*, 2012; Stoker, 2006; Tadayyon, 2013).

Besides their nutritional value, nuts are chosen to substitute meat as they are more sustainable than meat. A study by Fresán *et al.* (2019) showed no differences in greenhouse gas emissions between nuts and other plant-based meat ingredients. Despite their beneficial effects on human health and the environment, nuts possess some drawbacks. The primary drawback is being one of the most common causes of food allergies resulting in acute and severe allergic reactions (Asgar *et al.*, 2010). Moreover, nuts are considered to be expensive in markets. The high price is due to the freezing process needed to preserve nuts' sensory properties. Other treatments, such as heat treatments and vacuum packages, can also be employed. However, these treatments change the color of the nuts to an unattractive brown color that may decrease consumers' acceptability (Wilkinson, 2005).

JACKFRUIT

Jackfruit (*Artocarpus heterophyllus*) is a popular tropical fruit grown in Asia. It is well-known in the vegan community for its meat-like texture, enabling it to be processed into meat patties (chevon, beef, chicken) (Verma *et al.*, 2014; Ismail-Fitry & Abas, 2018; Abdullah, 2017), fishcake (Ngampeerapong *et al.*, 2019), meat floss (Natalia, 2020), pulled pork type recipes, and other substitutes of chicken, steak, crab, or tuna (Lopez *et al.*, 2015).

Unlike its ripe counterparts as a chicken meat substitute, unripe jackfruit, especially when fried in oil, excels, earning its nickname as the 'vegetable meat' (John *et al.*, 1992). Correctly seasoned and processed unripe jackfruit results

in no significant difference in taste, aroma, and texture of the end product compared to traditional meat. At the same time, it is more nutritious than conventional meat as it possesses a lesser amount of saturated fat and cholesterol with higher amounts of vitamins, minerals, carbohydrates, fiber (Table 2), and antioxidants that help to balance fluid and electrolyte levels, improve bone and skin health, and reduce the risk of cancer (Verma *et al.*, 2014; Ismail-Fitry & Abas, 2018; Abdullah, 2017; Goswami & Chacrabati, 2016; Swami *et al.*, 2012). Unfortunately, jackfruit only contains 1.9% protein, which is insignificant compared to meat (Table 3) (Ulloa *et al.*, 2017; Zuwariah *et al.*, 2018).

Jargon & Gasparro (2016) mentioned that food experts considered jackfruit to have the highest potential to be commercialized as a meat substitute, mainly due to its ease of processing methods since it inherently possesses meaty texture and its ability to absorb flavors from spices and herbs when cooked. Moreover, Ismail-Fitry, & Abas (2018) stated that using jackfruit as fat replacers in the manufacturing of chicken patties increased various physicochemical aspects such as texture, color, WHC (water holding capacity), and cooking yield. Its popularity has also been proven by the increased consumption of jackfruit as a meat substitute in Europe, the Middle East, and the USA (Witherup, 2019; Leite *et al.*, 2020). Aside from that, its cost-effective production can ensure food security for low-income populations and combat malnutrition (Goswami & Chacrabati, 2016; Byaruhanga *et al.*, 2019; Waghmare *et al.*, 2019). On the other hand, jackfruit possesses other concerns, such as being an allergen and invasive species. The leading cause of allergenicity is unclear, whether direct sensitization or cross-sensitization to pollen allergens (Prakash *et al.*, 2009). Its allergy can be

listed in birch pollen-related food allergies. Thus, jackfruit consumption for people who are allergic should be monitored. Jackfruit is considered to be an invasive species. Hence, introducing it into new regions should be performed with caution to avoid disadvantageous impacts on the local ecosystem and wildlife (Mileri *et al.*, 2012).

Abd El-Zaher (2008) and Miah *et al.* (2017) promoted planting jackfruit trees along highways, waterways, and railroads with a humid tropical climate and rich significant deep soils to add to the country's country's food supply. Its roots can benefit the soil structure, and its plant parts have varied usages, such as ripe bulbs can be transformed into powder, paste, chutney, or dried and fried in oil, salted into chips, and boiled. In addition, Roasted seed can also be dried then grounded to make flour. These benefits support the reason for jackfruit being produced worldwide, with an average of 1.25 million tons of fruit annually (Byaruhanga *et al.*, 2019). Jackfruit may be sustainable in its native regions, mainly Southeast Asia. Despite that, it creates a huge carbon footprint when exported in significant volume when catering to the vegetarian and vegan food markets in Europe and North America (Witherup, 2019; Leite *et al.*, 2020).

EGGPLANT

Eggplant (*Solanum melongena L.*) provides significant nutritive benefits that can potentially be used pharmaceutically (e.g., inhibitors of key enzymes relevant for type 2 diabetes and hypertension) as it is abundant in essential vitamins and minerals (Table 2), phenolics, antioxidants, and dietary fiber with low amounts of fat (Kumar & Chopra, 2016; Kumar & A. K., 2016; Kwon *et al.*, 2008; Gürbüz *et al.*, 2018). Unfortunately, its protein content is insignificant

(Table 3) since eggplants are promoted as a healthy carbohydrate rather than protein.

Eggplant is widely used in its native Indian cuisine and vegan and vegetarian cuisine as a meat substitute due to its texture, bulk, and earthy odor and flavor. Characteristic umami flavor emerges after eggplant undergoes seasoning and cooking process, such as steamed, stir-fried, pan-fried, deep-fried, barbecued, roasted, stewed, curried, pickled, or stuffed (similar to a stuffed chicken breast) (Behnke *et al.*, 2005). Salmon fillet (Shprintzen, 2012), minced beef (Sinnamon, 2009), and burger patty (with seitan and tofu) (Riya, 2020) are three of the many examples of eggplant substituting meat for a healthy and low-cost vegetarian cuisine.

Flores (2016) explained that the eggplant production process is carbon neutral, meaning that it does not emit carbon to the environment beyond the generated output. It even sequesters carbon as its production process exceeds the input carbon emission by 11 times, primarily when supported with renewable sources of inputs (e.g., organic fertilizers, biological pest control, biological mulching materials, and bioplastics as packaging materials). Creating a more sustainable and environment-friendly production system of eggplant can be done with these inputs to lower greenhouse gasses emissions.

Chong (2005); Krishna & Qaim (2007); Krishna & Qaim (2008); Asgharipour *et al.* (2020); Abney & Russo (1997) also stated that growing genetically modified eggplant will bring economic benefits to farmers, especially the resource-poor ones. This advantage outweighs the potential safety, moral concerns, and acceptability in substituting conventional eggplant with the genetically modified counterpart. Furthermore, growing the new genetically modified eggplant is more

sustainable as it reduces insecticide applications while increasing effective yields, reducing labor work, and maintaining its nutritional value.

Before eggplant can be considered a healthy and sustainable meat substitute, it needs different textures, tastes, visuals, and aroma developments to reach its potential as a proper meat alternative. In addition, continuous production of high-quality eggplant generates many difficulties during the cool season (Nothmann, 1985). Breeding incompatibilities pose difficulties for crossability and hybridization of cultivated eggplant with its wild relatives (Srinivasan, 2008).

CAULIFLOWER AND POTATO

Cauliflower (*Brassica oleracea var. botrytis*) is a low-calorie, mild-tasting, nutritious vegetable (Table 2) (Hamson, 1989). Besides legumes and lentils, cauliflower also decreases the risk of gout (suitable for a low uric acid diet) (Torralba *et al.*, 2012). It also has additional properties to substitute meat and seafood-based proteins when seasoned and cooked correctly, such as substituting chicken in meatballs, piccata when sliced into steaks, replacing egg in egg salad, and many other low-cost vegetarian dishes (Kordalis, 2019).

The protein content on cauliflower can vary from 37 - 48%, depending on the nutrients present during the cauliflower growth (Słupski *et al.*, 2008). Generally, cauliflower has an Indispensable Amino Acid (IAA) value of 35/100 grams (Abdul-Fadl, 2012). Upon processing, the individual amino acids in cauliflower would further vary, especially when comparing the raw to cooked cauliflower. Current studies express the protein quality of cauliflower-based on the number of essential amino acids present (EAA), which ranges between 43-45% (Słupski *et al.*, 2008).

Potatoes are commonly paired with other plant-based ingredients (especially cauliflower) to substitute meat as its soft flesh texture prevents them from standing alone as the main ingredient in low-cost yet healthy and Before processing them, delicious vegetarian cuisine (e.g., creamy soup, spicy samosas, burgers, and others) (Kordalis, 2019). A hundred grams of cooked, peeled potato contains 2 grams of protein, 0.1 grams of fats, and 2.3 dietary fibers. It also provides a wide range of vitamins and minerals (Table 2). Aside from that, the potato has 0.9 for its PDCAAS value, providing almost all essential amino acids (Table 3) (Haverkort & Struik, 2005; Kärenlampi & White, 2009; Hertzler *et al.*, 2020).

Substituting meat protein in sensorially appealing hybrid sausage with sunflower, pumpkin pit, pea protein powder, high moisture extrudate or texturized vegetable protein (Broucke & Van Royen, 2019) and its water being a suitable and economical substitute for meat extract in common bacteriological media types (Muzikár & Muzikárová, 1975) are two examples of potato usages related with meat. Literature regarding cauliflower and potatoes' potential as a meat substitute is still scarce as they do not closely resemble meaty texture, unlike jackfruit. Other than their texture, their visual, aroma, and taste need a lot of improvements (especially potato) until they can become a proper meat alternative compared to all of the previously mentioned ingredients. Few available literatures (Femenia *et al.*, 1997; Brindha & Rao, 2017; Aboulfadhl, 2012; El-Anany *et al.*, 2020) rather discuss cauliflower being agents of textural and water/oil binding to improve model food properties due to its high level of pectic-polysaccharide-rich fiber concentrates. This

results in enhanced beef burgers and sausages' quality and yield while at the same time acting as an inexpensive fat replacer of chicken skin in nuggets and a delicious source of protein, minerals, antioxidants, and crude fiber with lower fat and calorie.

The potato itself is a horticulture crop that accompanies 0.8% of land area and is responsible for 1% of the overall environmental agriculture footprint with high industrial value (Van Evert *et al.*, 2017; Lillywhite *et al.*, 2007). When aided with precision agriculture technology, potato's sustainability in terms of environmental impact and social profits can be enhanced even more (Van Evert *et al.*, 2017; Lillywhite *et al.*, 2007).

Yildirim & Guvenc (2005), Hall *et al.* (2004), Rani *et al.* (2020), Batabyal *et al.* (2016), and Singh *et al.* (2017) discussed the sustainability of cultivating cauliflower through intercrop, cover cropping, and organic farming systems. All of this has different benefits: (1) intercrop treatments provide the highest total yield and profitability; (2) crop cropping systems enhance agroecosystems by reducing soil erosion, increasing soil fertility, promoting beneficial insects, and decreasing weed competition; (3) organic farming is an effective and cost-efficient system supporting sustainability objectives, yet less profitable and productive than the conventional system. Hence, cauliflower can reach its sustainability peak (closely resembling natural systems) through the advancements of cover cropping systems by enhancing the cycling, diversity, stability, and capacity. Fortunately, researchers are still trying to improve the sustainability of cauliflower production, enhance its nutritional quality, and reduce waste.

COMPARISON OF THE PLANT-BASED MEAT

Table 1. Comparison of Nutritional Value, Sensory Properties, and Sustainability in Various Plant-Based Meat

Plant-Based Meat		Nutritional Value	Sensory Properties	Sustainability
Fungi	Mushroom	<ul style="list-style-type: none"> High in protein and fiber Lower fat, calorie, and sodium levels than meat Provide various vitamins, minerals, and antioxidants Better control of weight due to prolonged satiety, good for hypertension, and lesser chance of getting NCD 	<ul style="list-style-type: none"> Umami and meaty flavor Chewy texture It is usually processed through different methods to exert its roasty flavor and mimic meat sensorial properties. It has a fibrous structure that mimics meat. The substitutions of 50% and 80% (w/w) mushrooms prepared by searing provide similar moisture content and flavor. Unfortunately, searing decrease the firmness and chewy texture of the beef 	<ul style="list-style-type: none"> Grow easily and fast in small spaces and indoor areas, conserving soil and requiring less water and energy Utilizes agroindustrial byproducts (cocoa husks, soybean hulls, cottonseed peels, and crushed corn cobs) as their substrates to grow Contributes to a biologically diverse and healthy ecosystem Mushroom farms exert a less environmental carbon footprint. Only emitting 0.5 kg of CO₂ per pound of food consumed.
	Mycoprotein	<ul style="list-style-type: none"> High in protein (all essential amino acids) content and quality High fiber yet low in fat and carbohydrate Improve insulin sensitivity and glycemic profile Decrease total blood cholesterol and insulin concentrations Its fiber does not affect mineral absorption Higher RNA content than beef liver that might lead to gout (i.e., need processing to reduce it) 	<ul style="list-style-type: none"> High fibrous meat-like texture It needs to be added with egg albumen, color, and flavors to mimic meat Commercialized into sausage or patties after molding it to resemble meat (which is not complex) 	<ul style="list-style-type: none"> Slightly high carbon emission generation compared to chicken and pork More efficient usage of water and land than meat 45% of its environmental impact is sourced from the processing, 25% for frying, and 21% for components in the production, e.g., egg white (10%) and nitrogen fertilizer (11%) to grow fungal-substrate-crops

Pulses and Legumes	Lentils and Legumes	<ul style="list-style-type: none"> ● Rich in protein, fiber, PUFA, MUFA, various vitamins and minerals ● Provide all essential amino acids, except methionine and cysteine ● Have low GI value ● Reducing the risk of cardiovascular disease, cancer, and diabetes ● Induce satiety, which will promote weight loss 	<ul style="list-style-type: none"> ● Distinct taste and texture from real meat ● Not juice nor fatty ● Grainy texture ● Beany flavor 	<ul style="list-style-type: none"> ● Affect positively on biodiversity and soil health ● Create their nitrogen from the atmosphere ● Release up to seven times fewer greenhouse gases per area compared to other crops ● Have a long storage period, minimizing food waste
	Soy	<ul style="list-style-type: none"> ● High protein content and quality ● Rich in vitamin B12, Fe, and Ca ● Reduce blood cholesterol and heart disease risks ● It contains bioactive compounds that help reduce the risk of cancers (lung, breast colon, and prostate) 	<ul style="list-style-type: none"> ● Release off-flavor compounds (saponins and isoflavones): Beany and bitter flavor ● Its texture does not resemble meat ● Taste and texture can be improved by maintaining the moisture low, adding a solution of vegetable-based meat flavor, and genetic modification 	<ul style="list-style-type: none"> ● Its cultivation and processing use less land, water, and energy
Vegetables Proteins	TVP	<ul style="list-style-type: none"> ● Cholesterol-free (1% fat) ● Low sodium content, yet rich in fiber and protein ● Reduced risk of colon, breast, and prostate cancer ● Has PDCAAS score of almost 1.0 which suitable for malnutrition treatment ● Reduce the risk of breast, colon, and prostate cancer 	<ul style="list-style-type: none"> ● Fibrous and juicy texture ● Have meat-like taste ● Higher soy level decreases the palatability ● Emulsified version is more accepted than treated with oil ● Microwave-cooking method cause moisture loss and diminished beef flavor 	<ul style="list-style-type: none"> ● Its cultivation and processing use less land, water, and energy
	Seitan	<ul style="list-style-type: none"> ● High protein content and quality ● Provide various minerals, yet low in vitamins and fat levels ● Not suitable for gluten- 	<ul style="list-style-type: none"> ● Mild and neutral flavor ● Chewy texture ● Partially replaced the beef sausage with seitan colored 	<ul style="list-style-type: none"> ● It can reduce 50 points of environmental impact when seitan replaces 1000 servings of beef

	intolerant individuals	by red yeast rice, received positive reviews due to its unique taste and ability to improve the product's consistency	<ul style="list-style-type: none"> ● It May is not the complete substitute for beef in terms of its flavor, versatility in cooking, and texture since it is usually used as wheat-based food
Cottonseed	<ul style="list-style-type: none"> ● High protein content, vitamins, and minerals ● PDCAAS value need to be investigated ● Used for post-recovery treatment for kwashiorkor diseases ● Contains gossypol (less than 0.045% of free gossypol to be edible) 	<ul style="list-style-type: none"> ● The addition of texturized cottonseed may decrease beef aroma and flavor, but it improves stability during storage ● Bland flavor 	<ul style="list-style-type: none"> ● Needs further research
Nuts	<ul style="list-style-type: none"> ● High proteins, fibers, and fats, with a low amount of saturated fatty acids ● Rich in vitamins, minerals, and antioxidants ● A high PDCAAS value (0.5-0.9) provide all essential amino acids ● Reduce the risk of cardiovascular heart disease ● Reduce cholesterol ● Induce satiety and promote weight- loss ● Improve hair and nails quality ● One of the most common food allergies 	<ul style="list-style-type: none"> ● Oily and crunchy texture ● They are usually combined with other food additives to mimic the texture and flavor of the meat. ● Heat and vacuum-packaged treatment can change the nuts' color to unattractive brown color. ● The processing method of nuts to preserve its characteristics increases the production cost. 	<ul style="list-style-type: none"> ● No differences in greenhouse gases emission between the production of nuts and other-plant based meat ingredients.
Jackfruit	<ul style="list-style-type: none"> ● Less saturated fats and cholesterol, with a high amount of carbohydrates, fibers, 	<ul style="list-style-type: none"> ● Meat-like texture can be made into various food products such as 	<ul style="list-style-type: none"> ● Planting benefits the soil structure, and plant parts have

	<ul style="list-style-type: none"> vitamins, minerals, and antioxidant level ● Low in protein content (1.9%) ● Balance fluid and electrolyte levels ● Improve bone and skin health ● Reduce the risk of cancer ● Combat malnutrition ● One of the food allergens 	<ul style="list-style-type: none"> meat patties, meat floss. ● Fried unripe jackfruit has chicken meat characteristics ● When used as fat replacers for chicken patties, it increased various physicochemical aspects (texture, color, WHC, cooking yield) 	<ul style="list-style-type: none"> varied usages into food products ● Only sustainable in native regions as exporting the plant could create a huge carbon footprint
Eggplant	<ul style="list-style-type: none"> ● Inhibitor of key enzymes relevant for type 2 diabetes and hypertension ● Rich in dietary fibers, vitamins, minerals, phenolics, antioxidants, with low-fat content ● Low protein content ● Promoted as a healthy carbohydrate source rather than protein ● Reduce the risk of diabetes and hypertension 	<ul style="list-style-type: none"> ● Earthy odor and flavor ● Needs further improvement in texture, taste, visual, and odor to mimic meat 	<ul style="list-style-type: none"> ● Reduce the carbon emission
Cauliflower	<ul style="list-style-type: none"> ● Low calorie and fat levels ● Good source of vitamins and minerals ● Moderate protein content and quality ● Decrease risk of gout (good for low uric acid diet) 	<ul style="list-style-type: none"> ● Mild flavor ● The use of cauliflower as a meat substitute is still scarce ● Its texture does not closely resemble the meaty texture 	<ul style="list-style-type: none"> ● Reduce soil erosion ● Increase soil fertility ● Promote beneficial insects ● Reduce weed
Potato	<ul style="list-style-type: none"> ● Low protein content but has high PDCAAS value, providing almost all essential amino acids. ● Wide range of vitamins and minerals ● High in carbohydrate and calorie ● Low in fat and fiber 	<ul style="list-style-type: none"> ● Soft flesh texture (commonly combined with other ingredients) does not closely resemble meat. ● The use of potatoes as a meat substitute is still scarce ● Further improvement regarding visual, 	<ul style="list-style-type: none"> ● Horticulture crop ● Environmental impact and social profits can be enhanced with precision agriculture technology.

aroma, taste, and texture need to be done to mimic real-meat sensory properties

Table 2. Comparison of Nutritional Value in Various Plant-Based Meat

Plant-Based Meat	Nutrients						References
	Carbohydrate /100 g	Protein /100g	Fat /100g	Fiber/ 100g	Minerals/ 100g	Vitamin /100g	
Fungi							
White button mushroom	4.08 g	39 g	0.3 g	19 g	Zn (8 mg), P (138 mg), Fe (17 mg), Ca (38 mg)	B3 (3.88 mg), B1 (65 µg), B6 (77 µg), B7 (9 µg), B9 (35 µg)	Myrdal Miller <i>et al.</i> (2014); Feenerly <i>et al.</i> (2014); Patinho <i>et al.</i> (2019); FoodData Central (2021)
Mycoprotein	9 g	11 g	2.9 g	6 g	Se (20 mg), Zn (9 mg), Na (4 mg), Fe (0.5 mg)	B2 (0.23 mg), B3 (0.35 mg), B5 (0.25 mg)	Finnigan <i>et al.</i> (2019); Souza <i>et al.</i> (2019); FoodData Central (2021)
Pulses and Legumes							
Soy	32.9 g	24.96 g	6.63 g	6.35 g	Fe (6.05mg), Na (267 mg), Zn (4.29mg), P (726 mg), Mg (313 mg), Ca (338 mg), K (2480 mg)	B1 (0.26 µg), B2 (0.15µg), B3 (0.87 µg), B6(0.24µg), B9 (0.87µg), B12 (0.87 µg), A (7.3µg)	Fresan <i>et al.</i> (2019); FoodData Central (2021)
Legumes and Lentils	37.2 g	24.63 g	1.06 g	10.7 g	Fe (6.51mg), Ca (35 mg), Na (6 mg), Mg (78 mg), K (677 mg)	A (2 µg), B1 (0.9 mg), B2 (0.2 mg), B3 (2.6 mg), B6 (0.5 mg), B9 (479 µg), C (4.5 mg)	Rizzo & Baroni (2018); Yadav, McNeil & Stevenson (2007); FoodData Central (2021)
Vegetable proteins							
TVP	33.92 g	24.96 g	6.63 g	6.35 g	Fe (6.05 mg), Zn (4.29 mg), Na (267 mg),	A (7.3 µg), B1 (0.3 µg), B2 (0.2 mg),	Fresan <i>et al.</i> (2019); FoodData Central (2021)

					Ca (333 mg), Mg (300 mg), P (708 mg)	B3 (0.9 µg), B6 (0.24 µg), B9 (121 µg), B12 (0.87 µg)	
Seitan	61.87 g	24 g	1.9 g	14.2 g	Na (320 mg), Ca (5.5 mg), K (250 mg), Mg (40 mg), Zn (1 mg), Cu (14.4 mg), Fe (7.8 mg)	A (3 µg), B1 (0.03 mg), B2 (0.03 mg), B3 (3.7 mg), B6 (0.31 mg), B9 (48 µg)	Bogueva <i>et al.</i> (2019); FoodData Central (2021)
Cottonseed	36.1 g	33 g	14 g	6 g	Na (35 mg), Mg (760 mg), P (1680 mg), K (1870 mg), Mn (2.26 mg), Ca (504 mg), Fe (12.7 mg), Cu (1.2 mg), Zn (11.7 mg)	B1 (2.22 mg), B2 (0.42 mg), B5 (0.5 mg), B6 (0.8 mg), B9 (242 µg), C (2.5 mg), E (0.8 mg), K (43 µg)	Thirumalaisamy <i>et al.</i> (2016); FoodData Central (2021)
Nuts	21.6 g	18.12 g	11.6 g	3.01 g	Fe (3.62 mg), Zn (3.18 mg), Na (162 mg), P (481 mg), Mg (270 mg)	A (17.08 ug), B1 (0.13 ug), B2 (0.05 ug), B3 (2.47 ug), B6 (0.13 ug), B1 (1.02 ug), B9 (56.54 ug), E (36.35 mg)	Fresan <i>et al.</i> (2019); FoodData Central (2021)
Jackfruit	23.2 g	2 g	0.2 g	5.6 g	Ca (73 mg), Fe (1.9 mg), P (57 mg), K (323 mg), Na (48 mg)	A (30 IU), C (14 mg), B1 (0.15 mg), B2 (0.2 mg), B3 (0.4 mg), B6 (0.3 mg)	Janick (2008); Swami <i>et al.</i> (2012); FoodData Central (2021)
Eggplant	5.88 g	1 g	0.2 g	3 g	Mn (0.1 mg), K (299 mg), Zn (0.12 mg), Ca (9 mg), Mg (14 mg)	B1 (0.08 mg), B3 (0.73 mg), C (1.29 mg), A (14 ug)	Goldstein (2017); FoodData Central (2021)
Cauliflower	4.97 g	1.9 g	0.3 g	2 g	Mg (16 mg), P (47 mg), Ca (24 mg), Fe (0.42 mg), K (299 mg)	B9 (57 ug), C (48.2 mg), B2 (0.06 mg), B3 (0.51 mg)	Aboufadel (2012); FoodData Central (2021)

Potato	83.1 g	2 g	0.1 g	2.3 g	Ca (6.4 mg), Fe (0.43 mg), Mg (21 mg), Mn (0.1 mg), P (50 mg), K (418 mg), Na (27 mg), Zn (0.34 mg)	B1 (0.08 mg), B2 (0.45 mg), B6 (0.22 mg), B9 (0.02 mg), C (12 mg), E (0.1 mg)	Haverkort & Struik (2005); FoodData Central (2021)
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Table 3. Comparison of Amino Acid in Various Plant-Based Meat

Plants		Amino Acids	References
Fungi	Mushroom	Glutamic and Aspartic acid	Patinho <i>et al.</i> (2019)
	Mycoprotein	Histidine, valine, leucine, tryptophan, isoleucine, methionine, threonine	Finnigan <i>et al.</i> (2019)
Pulses and Legumes	Soy	Contain all essential amino acids, except methionine and cysteine	Erskine (2009)
	Legumes and Lentils		
Vegetable Protein	TVP	Contains all essential amino acids with a limited amount of methionine	Featherstone (2015)
	Seitan	Isoleucine, valine, and low in lysine	Bogueva <i>et al.</i> (2019)
	Cottonseed	Lysine, threonine, methionine	Thirumalaisamy <i>et al.</i> (2016)
	Nuts	Contain all essential amino acids (amount varied depending species)	Pizzorno <i>et al.</i> (2010)
	Jackfruit	Contain all essential amino acids with tryptophan and tyrosine as the highest	Swami <i>et al.</i> (2012)
	Eggplant	High in glutamine	Goldstein (2017)
	Cauliflower	Lysine, alanine, aspartic, leucine	Aboulfadl (2012)
	Potato	Lysine, methionine, tryptophan, isoleucine, leucine, valine, phenylalanine, tyrosine	Kärenlampi & White (2009)

CONCLUSION

Meat substitutes can be sourced from various plant-based sources. Mushrooms, mycoprotein, soy, TVP, and seitan have a high potential to become a healthier and more sustainable meat alternative due to their sensory properties (umami flavor, fibrous to meat-like texture) and nutritional value (high protein quality, vitamins, and minerals yet low in fat and sodium levels). However, there are some challenges for each alternative, such as mushrooms' wide variety, mycoprotein production cost that is similar to meat, beany and grainy texture and nodes of soy-based products, increased seitan production that may negatively impact the environment, and low protein content of jackfruit. On the other hand, nuts, cauliflower, potato, and eggplant require a lot of sensory improvement to mimic meat characteristics despite their environmental and financial (except for nuts) benefits. Additionally, they also have low protein content and quality. Meanwhile, cottonseed proteins have toxic gossypol that is essential to be removed, and further research regarding their sustainability and nutritional value needs to be done. In terms of legumes and lentils, their processing reduces some nutritional components while also providing distinct taste and texture from meat.

The potential of using other food sources for a more sustainable and healthier alternative to meat is still not fully discovered yet, meaning that deeper research is recommended.

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