Nutritional Potential of Underutilized Fruits of India: A Review

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Abstract

Food insecurity remains one of the major challenges of the present time in many developing countries. The deficiency of essential nutrients like vitamins and minerals in the diet leads to many diseases. These deficiencies can be overcome by increasing the diversity in the diet by including fruits. However, a large section of the society does not have access to conventional fruits, which are costly. India is rich in biodiversity and produces many fruits rich in these nutrients. However, many such fruits remain underutilized because of the lack of post-harvest technologies. These fruits are rich in vitamins and minerals and are cheaper and locally available. The proper exploitation of these fruits can keep the population healthy. This review discusses the nutritional potential of some of the underutilized fruits of India.

Keywords: Underutilized fruits; Nutrition; Physicochemical; Phytochemical; Food security

I. INTRODUCTION

Today, the world faces various challenges, including hunger, malnutrition, poverty, environmental changes, pandemic, and population explosion. As a result, ensuring society's long-term and widespread access to sufficient, nutritious, healthful, and inexpensive food is a major concern. [1], [2]. Because of the explosive growth of the population, more and more food must be produced and made available for human consumption. While the modern agriculture and food production system has helped increase production and has reduced the proportion of the hungry people on the planet to half. These methods have also contributed to environmental issues like reducing biodiversity, increased emission of greenhouse gasses, contamination, shortages of ground water, etc. [2]. Out of millions of plant species known globally, only a handful (roughly 120) are cultivated and consumed as food. Only nine species supply 75 % of the plant-derived energy globally [3]. Dietary variety is an excellent source of nutrients (Ghosh-Jerath et al., 2016). According to the World Health Organization report, the global prevalence of undernourishment climbed by 1.5 percentage points in 2020, reaching 9.9%, with about 12% of the global population suffering from acute food insecurity. The number of people facing hunger increased by around 118 million this year compared to 2019. Of this increase, about 46 million were in Africa, 57 million in Asia, and about 14 million in Latin America and the Caribbean. The global prevalence of moderate or severe food insecurity has been slowly rising since 2014. This growth in 2020 was the same as the previous five years combined. About 2.37 billion people in the world (one in three) did not have adequate access to food in 2020. All forms of malnutrition increased during this period. An estimate of around 22 % of children under five years of age was suffering from stunted growth, approximately 5.7 % were overweight, and about 6.7 % were suffering from wasting in 2020. Asia and Africa account for more than 9 out of 10 children with stunting and wasting and more than 7 out of 10 of all the children affected by overweight worldwide [5]. The situation in India is also not very good. India ranked 101st among 116 countries with sufficient data to score in the Global Hunger Index 2021 with 27.5. The Global Hunger Index ranks countries based on child stunting and wasting, undernourishment, child mortality, etc. India has a ‘serious’ level of hunger and undernutrition. According to this report, about 34.7 % of children under five years of age are affected with stunting, and 17.3 % are suffering from wasting [6].

One of the primary reasons for the multiple burdens of malnutrition is poor diet. Improvement in dietary diversity is a proven, cost-effective method of fighting malnutrition [4]. In the last 50 years, the world's diets have largely homogenized, with only a few species dominating energy consumption [2]. This has resulted in the neglect of indigenous food crops that are nutrient-dense and easily accessible to residents. The lack of dietary diversity reduces the population's nutritional intake and leads to a loss of income from these indigenous food crops. Increased consumption of fruits and vegetables in the diet aids in illness prevention. Also, fruits and vegetables are a source of dietary fiber that helps lower the fat and cholesterol accumulation in the body. A large number of these fruits are semi-domesticated and wild. The majority of these fruits are underutilized due to a lack of public awareness about their nutritional value [1]. Furthermore, there is no post-harvest technology for gathering and preserving these fruits. In addition, most of these fruits are not accepted in the market in their fresh form because of their unappealing taste [7]

As a result, research efforts should explore the potential of these food crops and popularize their advantages.

II. PHYSIOCHEMICAL AND NUTRITIONAL COMPOSITION OF UNDER-UTILIZED FRUITS

The underutilized fruits are abundant in nutritional content and phytochemicals. They can help to prevent a variety of diseases.

Source of carbohydrates

Carbohydrates are the energy-yielding compound; sucrose, glucose, fructose galactose are the simplest or monomer unit of carbohydrates. Fructose is the major monomer unit found mostly in fruits that provides energy following metabolism. It is also present in underutilized fruits in an adequate amount, which is better in quantity than other fruits [8]. Table 1 [9] lists the proximate analysis of the total carbohydrates present in some underutilized fruits. The total carbohydrates in the fruits comprise the dietary fibers, starch, and other sugars. The dietary fibers are not digested by the human body and thus do not give energy; however, starch and other sugars provide energy. Table 2 [9] provides an overview of the sugar content of some of the important, underutilized fruits found in India. Tamarind is grown abundantly in Asia, and its fruits have a sweet-sour taste. The fruits of Tamarind are rich in sugar. However, they have a sour taste because of the presence of tartaric acid [10]. The tamarind fruits have a fragile pod filled with yellow or brown fibrous pulp, which is acidic in taste [11] India is one of the largest producers of tamarind. This fruit is used in many Indian food preparations [12].

Source of dietary fibers

Dietary fibers are complex heterogeneous polysaccharides, including cellulose, hemicellulose, pectin, lignin gum, etc. [13]. They are not digested in the human gastrointestinal tract. The intake of dietary fibers has several health benefits, including decreased cholesterol levels in the blood, increased stool bulk, etc [13]. The regular intake of a sufficient quantity of dietary fibers has proven to reduce the risk of cardiovascular diseases [14], diabetes [15], hypertension [16], and some gastrointestinal diseases [17]. Nowadays, people are interested in eating functional food rich in dietary fibers. Cereals, fruits, vegetables, and nuts are the primary sources of dietary fibers. However, studies have suggested that the dietary fibers from fruits are more beneficial than the other sources as they have a better soluble to insoluble dietary fiber ratio, higher fat retention capacity, and low energy value [18]. Conventional fruits are costly, and their consumption is impossible for every individual in society. Many underutilized fruits are rich in dietary fibers. Table 1 contains the list of underutilized fruits and their dietary fiber content.

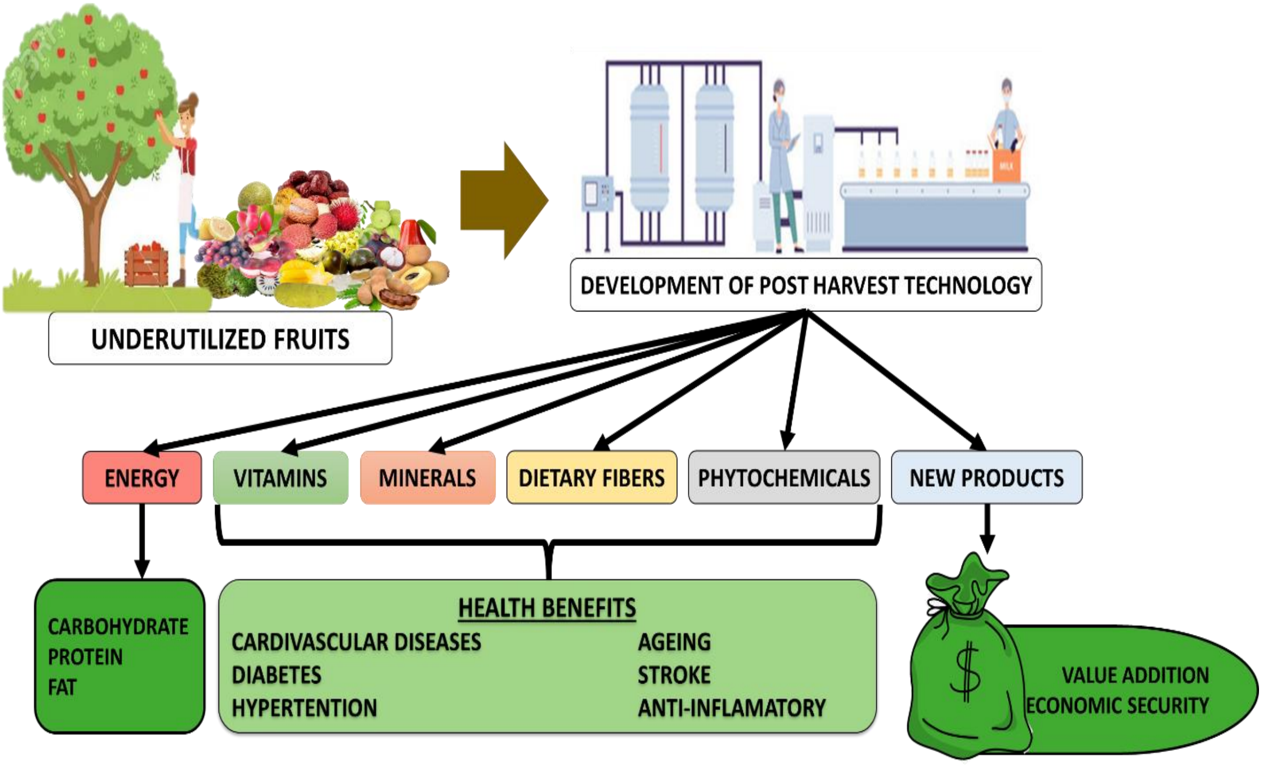

Fig. 1: Role of under-utilized technologies in utilizing the under-utilized fruits.

Table 1: Proximate analysis of some under-utilized fruit of India.

Name of Fruits	Protein	Fat	Dietary Fibres			Total Carbohydrate
			Total	Insoluble	Soluble	
Bael fruit (*Aegle marmelos*)	2.63	0.57	6.31	3.31	3	28.21
Custard Apple (*Annona squamosa*)	1.62	0.67	5.1	3.17	1.93	20.38
Gooseberry (*Emblica officinalis*)	0.34	0.16	7.75	6.2	1.55	14.39
Jack fruit (*Artocarpus heterophyllus*)	2.74	0.15	3.62	2.21	1.41	14.01
Jambu fruits (*Syzygium samarangense*)	0.82	0.17	3.07	2.4	0.67	12.3
Karonda fruit (*Carissa carandas*)	1.15	1.67	7.25	5.87	1.38	2.87
Litchi (*Litchi chinensis*)	0.99	0.26	1.34	0.81	0.53	11.41
Mangosteen (*Garcinia mangostana*)	0.63	0.24	1.87	1.23	0.64	11.41
Manila tamarind (*Pithecellobium*)	3.56	1.14	4.4	3.3	1.1	13.54
Musk melon (*Cucumis melon*)	0.42	0.35	1.51	0.84	0.67	4.24
Palm fruit (*Borassus flabelifer*)	0.5	0.12	2.4	1.87	0.53	4.92
Phalsa (*Grewia asiatica*)	1.66	0.14	4.54	3.44	1.09	15.09
Pummelo (*Citrus maxima*)	0.68	0.42	0.8	0.49	0.31	10.64
Rambutan (*Nephelium lappaceum*)	0.68	0.16	1.02	0.71	0.3	16.84
Sapota (*Achras sapota*)	0.92	1.26	9.6	8.46	1.14	13.9
Soursop (*Annona muricata*)	0.74	0.94	4.95	3.79	1.16	11.94
Star fruit (*Averrhoa carambola*)	0.79	0.39	2.81	2.17	64	4.51
Tamarind (*Tamarindus indica*)	2.92	0.15	5.31	3.73	1.58	67.35
Wood Apple (*Limonia acidissima*)	3.14	3.62	5.21	3.77	1.44	7.52
Zizyphus (*Zizyphus jujube*)	1.34	0.35	3.73	2.71	1.02	9.4

All the units are in g per 100 g of edible fruits.

Table 2: Starch and individual sugar content of some underutilized fruits.

Name of Fruits	Total available carbohydrate	Total starch	Fructose	Glucose	Sucrose
Bael fruit (*Aegle marmelos*)	23.55	7.2	9.58	2.65	4.12
Custard Apple (*Annona squamosa*)	13.69	0.34	9.1	4.25	
Gooseberry (*Emblica officinalis*)	3.95	0.56	2.1	1.29	
Jack fruit (*Artocarpus heterophyllus*)	12.71	0.5	4.12	3.33	4.76
Jambu fruits (*Syzygium samarangense*)	8.32	1.48	4.47	2.21	0.16
Karonda fruit (*Carissa carandas*)	2.55	0.8	1.19	0.56	
Litchi (*Litchi chinensis*)	9.3		4.05	2.17	3.08
Mangosteen (*Garcinia mangostana*)	9.41	0.5	5.12	1.67	2.12
Manila tamarind (*Pithecellobium*)	12.63	0.5	3.45	4.12	4.56
Musk melon (*Cucumis melon*)	2.99		0.62	0.71	1.65
Palm fruit (*Borassus flabelifer*)	1.03	0.84	0.17	0.02	
Phalsa (*Grewia asiatica*)	13.75	0.75	6.12	4.66	2.22
Pummelo (*Citrus maxima*)	4.85	0.46	2.09	1.44	0.86
Rambutan (*Nephelium lappaceum*)	15.8		8.78	6	1.02
Sapota (*Achras sapota*)	12.3		8.6	2.85	0.85
Soursop (*Annona muricata*)	9.95	0.12	7.99	1.66	0.18
Star fruit(*Averrhoa carambola*)	3.95		2.22	1.73	
Tamarind(*Tamarindus indica*)	52.88		12.31	14.53	26.04
Wood Apple(*Limonia acidissima*)	6.6	2.79	1.38	1.41	1.02
Zizyphus (*Zizyphus jujube*)	8.29		4.3	2.98	1.01

All the units are in g per 100 g of edible fruits.

Source of fat and fatty acids

Fat is the essential component in the diet, and it regulates various functions in the human body. It is also used as an energy source when deficiency of carbohydrates. The fatty acid requirements are higher during pregnancy, lactation, and growth [8]. Studies show that the long-chain Omega 3 fatty acids like eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA) have anti-inflammatory properties and are beneficial against cardiovascular diseases and obesity [19]. Long-chain poly unsaturated fatty acids, including α-Linoleic acids, are the predominant component of the phospholipid bilayer in the human cell membrane. Therefore, they an essential for maintaining essential cellular functions [20]. The deficiency of these essential fatty acids in the body can cause inflammatory auto immune diseases, cardiovascular diseases, and cancer. A balanced omega-3 and omega-6 fatty acids ratio is essential for healthy cellular functions and brain activity. The current typical diet has low levels of omega-3 fatty acids, which can cause hyperactivity, attention deficit, arthritis, cancer, hypertension, diabetes, asthma, atherosclerosis, Alzheimer's, Parkinson's, etc [21]. Humans can produce long-chain polyunsaturated fatty acids from their precursors like Linoleic acid and α-Linoleic acids [21]. Table 3 [9] lists the fatty acid content of some of the underutilized fruits. Although fruits are not the primary source of essential fatty acids, these underutilized fruits can help in increasing dietary diversity and add to the dietary intake of essential fatty acids in the economically poor section of society.

Wood Apple (*Limonia acidissima*) is indigenous to India and Srilanka and is commonly found throughout the plains of India. It is also known by various other names like monkey apple, elephant apple, Kainth, Kotha, etc [22]. The fruit is used in many food preparations like beverages, jams, fruit crush, etc. It is also used in many folk medicines. The fruit's outer shell is hard while the pulp is sour and the seeds are embedded. The fruit is a good source of unsaturated fatty acids containing about 1435 mg mono-unsaturated fatty acids and 529 mg poly-unsaturated fatty acids per gram of 100 g. The fruit's Linoleic acid (799 mg per 100g) and α-Linoleic acid (636 mg per 100 g) content is also very high among fruits.

Table 3: Fat content of some under-utilized fruit of India

Name of Fruits	**Linoleic acid**	**α-Linoleic acid**	**Total Saturated Fatty acids**	**Total mono-unsaturated fatty acids**	**Total poly unsaturated fatty acids**
Bael fruit (*Aegle marmelos*)	87.01	66.18	190	112	154
Custard Apple (*Annona squamosa*)	78.56	53.47	138	39.74	132
Gooseberry (*Emblica officinalis*)	47.41	27.83	38.48	23.93	75.24
Jack fruit (*Artocarpus heterophyllus*)	22.63	15.44	37.66	44.27	38.07
Jambu fruits (*Syzygium samarangense*)	42.4	6.37	66.49	20.73	48.77
Karonda fruit (*Carissa carandas*)	45.12	7.48	66.81	24.12	52.8
Litchi (*Litchi chinensis*)	51.98	26.91	91.48	45.83	78.89
Mangosteen (*Garcinia mangostana*)	20.48	65.92	176	165	88.8
Manila tamarind (*Pithecellobium*)	6.01	13.48	27.81	33.45	19.49
Musk melon (*Cucumis melon*)	97.34	61.33	92.94	25.18	159
Palm fruit (*Borassus flabelifer*)	50.64	25.78	33.36	38.32	76.42
Phalsa (*Grewia asiatica*)	362	18.66	164	167	381
Pummelo (*Citrus maxima*)	134	53.21	115	41	187
Rambutan (*Nephelium lappaceum*)	160	202	144	160	362
Sapota (*Achras sapota*)	233	125	389	255	358
Soursop (*Annona muricata*)	77.98	54.02	135	38.54	132
Star fruit (*Averrhoa carambola*)	151	39.9	20.77	33.62	191
Tamarind (*Tamarindus indica*)	4.99	12.86	27.26	34.89	17.85
Wood Apple (*Limonia acidissima*)	799	636	877	595	1435
Zizyphus (*Zizyphus jujube*)	27.18	8.07	119	126	35.25

All the units are in mg per 100 g of edible fruits.

Source of protein

Proteins are essential constituents of the human diet. They are known as building block materials of the body and are a necessary component of muscles, cells, tissues, and vital fluids. Proteins regulate metabolic processes in the form of hormones and enzymes. Protein as antibodies fight pathogens and keep the body healthy. Protein deficiency leads to many diseases like malnutrition, marasmus, kwashiorkor (in baby), etc. [8]. The requirement of dietary protein has two components. First, fulfilling the requirement of total nitrogen to synthesize non-essential amino acids, and second, fulfilling the need for essential amino acids in the body [23]. Apart from acting as the building blocks for the proteins, amino acids play a vital role in various metabolic processes like transcription, translation, post-transcriptional modifications, post-translational modifications, mRNA degradation, RNA transport, and modification of chromatin [24], [25]. Therefore, intake of essential amino acids is important. Tables 4 and 5 [9] show under-utilized fruits' and their essential and non-essential amino acid content, respectively.

Table 4: Essential amino-acid content of some under-utilized fruits of India

Name of Fruits	Arginine	Histidine	Isoleucine	Leucine	Lysine	Methionine	Phenylalanine	Threonine	Tryptophan	Valine
Bael fruit (*Aegle marmelos*)	3.86	2.52	3.29	5.86	4.86	1.26	4.81	4.16	0.98	4.62
Custard Apple (*Annona squamosa*)	3.87	5.25	2.26	4.88	4.26	0.99	4.16	4.37	0.86	4.86
Gooseberry (*Emblica officinalis*)	3.87	2.4	1.94	4.25	4.06	0.73	4.85	3.3	0.75	2.99
Jack fruit (*Artocarpus heterophyllus*)	3.22	1.63	3.49	6.76	3.32	0.54	4.49	4.35	0.62	5.18
Jambu fruits (*Syzygium samarangense*)	1.54	2.38	5.21	8.52	1.99	1.85	5.63	5.32	0.83	6.99
Karonda fruit (*Carissa carandas*)	4.21	3.08	2.86	4.85	1.98	1.25	3.86	3.66	0.85	4.62
Litchi (*Litchi chinensis*)	2.24	1.84	4.73	8.08	4.95	1.46	5.39	4.74	0.74	6.05
Mangosteen (*Garcinia mangostana*)	2.64	2.51	4.54	9.1	2.83	1.29	6.21	6.87	1.21	5.36
Manila tamarind (*Pithecellobium*)	3.35	2.78	3.64	5.6	2.21	1.26	4.35	4.81	1.14	4.92
Musk melon (*Cucumis melon*)	2.51	0.88	2.72	3.67	2.27	0.89	1.62	2.81	0.52	3.06
Palm fruit (*Borassus flabelifer*)	3.85	3.14	4.16	3.74	2.35	0.85	2.76	4.32	0.44	4.31
Phalsa (*Grewia asiatica*)	5.86	1.91	4.44	7.19	2.82	2.05	4.84	4.18	0.66	5.76
Pummelo (*Citrus maxima*)	5.19	1.76	2.81	4.69	3.78	0.87	2.45	3.19	0.48	4.23
Rambutan (*Nephelium lappaceum*)	6.75	3.38	1.9	4.66	3.54	1.12	2.41	4.01	1.25	4.77
Sapota (*Achras sapota*)	6.7	3.61	4.45	6.62	4.67	1.02	4.99	4.56	0.84	5.91
Soursop (*Annona muricata*)	3.63	2.93	2.8	5.67	5.3	0.91	4.07	3.89	0.87	4.21
Star fruit (*Averrhoa carambola*)	5.37	2.6	3.61	5.61	3.14	0.86	2.5	4.32	0.93	4.51
Tamarind (*Tamarindus indica*)	3.15	2.58	3.28	5.58	5.18	0.84	5.46	3.26	0.85	4.02
Wood Apple (*Limonia acidissima*)	7.54	1.2	3.93	3.17	2.58	0.85	2.98	2.01	0.85	3.72
Zizyphus (*Zizyphus jujube*)	5.51	1.84	4.09	3.59	1.5	1.06	3.47	2.35	0.88	4.67

All the units are in grams per 100g of the edible fruits.

Table 5: Non-essential amino acid content of some under-utilized fruits of India.

Name of Fruits	Alanine	Aspartic acid	Glutamic Acid	Glycine	Proline	Serine	Tyrosine	Cystine
Bael fruit (*Aegle marmelos*)	4.82	18.2	14.26	3.86	5.26	5.4	2.43	0.65
Custard Apple (*Annona squamosa*)	7.08	18.32	17.32	4.96	4.82	5.12	1.97	0.48
Gooseberry (*Emblica officinalis*)	6.47	14.9	23.9	5.01	4.48	4.95	2.6	0.61
Jack fruit (*Artocarpus heterophyllus*)	6.16	26.27	9.24	5.4	4.42	5.39	3.22	0.5
Jambu fruits (*Syzygium samarangense*)	7.04	11.99	15.22	6.59	6.09	5.54	3.23	0.93
Karonda fruit (*Carissa carandas*)	5.62	15.38	15.62	3.85	3.82	4.85	3.12	1.18
Litchi (*Litchi chinensis*)	10.56	11.65	16.07	5.56	5.72	5.16	2.92	1.22
Mangosteen (*Garcinia mangostana*)	7.6	14.16	13.3	7.07	4.27	4.76	2.86	0.81
Manila tamarind (*Pithecellobium*)	6.25	13.85	16.45	4.21	3.56	4.86	1.85	0.59
Musk melon (*Cucumis melon*)	12.94	9.99	25.89	3.76	3.2	4.82	1.69	0.8
Palm fruit (*Borassus flabelifer*)	6.84	13.86	16.82	4.56	4.17	5.18	1.25	1.1
Phalsa (*Grewia asiatica*)	5.27	12.12	18.54	4.96	5.31	5.01	2.18	1.1
Pummelo (*Citrus maxima*)	7.62	27.7	12.35	2.74	9.41	4.78	1.83	0.81
Rambutan (*Nephelium lappaceum*)	5.87	12.73	28.08	6.62	4.66	2.69	2.7	0.76
Sapota (*Achras sapota*)	5.92	10.9	10.63	5.2	3.8	5.6	3.35	0.57
Soursop (*Annona muricata*)	4.3	15.84	19.99	5.07	5.69	5.17	3.31	0.74
Star fruit (*Averrhoa carambola*)	6.1	17.4	18.55	4.45	3.35	4.67	3.89	0.67
Tamarind (*Tamarindus indica*)	4.34	12.28	15.19	4.01	5.04	3.51	2.88	0.71
Wood Apple (*Limonia acidissima*)	5.51	31.42	15.65	2.92	4.2	4.26	2.51	0.41
Zizyphus (*Zizyphus jujube*)	4.62	31.84	17.33	3.14	2.52	3.86	3.46	1.54

All the units are in grams per 100g of the edible fruits.

Source of minerals

Minerals are inorganic molecules present in all tissues and cells and help in a plethora of bodily functions. Humans require many minerals in their diet to maintain their metabolic processes [26]. These minerals may be macro and micro based on the amount of utilization by the human body. Minerals are essential for the absorption and functioning of vitamins in the human body [26] The minerals are required in precise quantities in the body. Both deficiency and abundance of these mineral nutrients and trace elements are known to cause various health disorders [27]. The primary source of minerals present in plants and animals is soil. Plant-based foods contain almost all the essential minerals. The levels of micro-minerals in humans can be regulated by dietary diversification, mineral supplementation, or food fortification [27]. The diversification of diet is the most economical method of improving mineral nutrition. Many under-utilized fruits are a good source of these minerals (Table 6) [9]. Calcium is the most highly used mineral in the human body. It plays an important role in building strong bones and teeth and helps in various intracellular functions [26]. The deficiency of calcium causes osteoporosis in adults and rickets in growing individuals. Under-utilized fruit Kadam (*Neolamarckia cadamba*) is a good source of calcium. It is a rich source of vitamins, minerals, phenolics, and alkaloids [7]. Chromium is a mineral that humans require in trace quantities. Chromium deficiency causes decreased glucose tolerance, insulin sensitivity, and diabetes [26].

Under-utilized fruits like Jambu fruit and star fruit are a good source of chromium [9]. Jambu fruit, commonly known as wax jambu is an evergreen tree of Asian origin. This pear-shaped pink fleshy fruit of 5-12 cm length is rich in phytochemicals and is eaten raw or cooked with sauce [28]. Star fruit (*Averrhoa carambola*) is grown in South-East Asia. The fruit is yellow and sour tasting. It is a rich source of antioxidants and minerals. It is eaten raw and in different food preparations like salads and pickles [29]. Copper is an essential mineral for human health; at the same time, it is toxic when ingested in larger quantities.

The metabolism of copper is related to many other mineral metabolisms. The deficiency of copper causes secondary iron deficiency [27]. Karonda is rich in copper. Karonda (*Carissa carandas*) is a tropical plant native to India. The fruits of Karonda are globular pinkish-white and turn to purple on ripening. The fruit is rich in anthocyanin, vitamins, and minerals. It is used for the treatment of many diseases. The unripe fruit is used to treat liver disfunction and the ripe fruit for vitamin C deficiencies. The fruit is also known for its anti-diabetic, analgesic, and anti-inflammatory properties [30] Almost one-third of the world population is estimated to suffer from Zinc deficiency. Zinc deficiency is mainly found in under-developed countries due to the poor diet. Zinc deficiency causes many diseases like chronic liver disease, chronic renal disease, diabetes, and cancer.

Under-utilized fruits like tamarind, manila tamarind (*Pithecellobium dulce*), and rambutan (*Nephelium lappaceum*) are good sources of Zinc [9] Manila tamarind is an ornamental plant belonging to the Leguminosae family. It is of medium height found in India's Uttar Pradesh, Andhra Pradesh, Tamil Nadu, and Maharashtra region. The fruits are aril, attractive and astringent in taste, and raw [31] Rambutan is a tropical fruit belonging to the Sapindaceae family. The fruit is grown in Malaysia, Indonesia, Thailand, and India. It is an oval fruit with a red pericarp having soft thorns. The fruit has a refreshing taste and is eaten raw and in various food preparations [32].

Source of vitamins

Vitamins are organic compounds required in trace amounts and regulate many vital functions. Vitamin deficiency leads to an increased risk of developing infections, allergies, and inflammatory diseases. They are broadly classified based on solubility in water-soluble and fat-soluble. Vitamins C and B complex are soluble in water, and vitamins A, D, E, and K are soluble in fat [8]. Table 7 lists some under-utilized fruits rich in water-soluble vitamins [9].

A. Vitamin B complex

i) Thiamine (Vitamin B1)

It is an essential member of the Vitamin B complex. Thiamine is phosphorylated to thiamine pyrophosphate, a coenzyme for many enzymes, including pyruvate dehydrogenase and α-ketoglutarate dehydrogenase [33]. The deficiency of thiamine in the body leads to metabolic acidosis and, if left untreated, can affect the peripheral nervous system and cardiovascular system, a disease known as beriberi [34]. Thiamine deficiency is caused by inadequate intake, poor gastrointestinal absorption due to disease or surgery, and increased metabolism. The thiamine deficiency is often found in patients with a history of alcohol abuse, AIDS, and cancer [34].

ii) Riboflavin (Vitamin B2)

Riboflavin and its active forms are cofactors for enzymatic reactions in the citric acid cycle and fatty acid oxidization. Fatty acid oxidation plays an important role in activating, proliferation, and differentiation immune cells [33]. This suggests that riboflavin deficiency may affect the immune response. The deficiency of Riboflavin is associated with diseases like scrotal dermatitis, glossitis, angular stomatitis, and seborrheic dermatitis [8]. Riboflavin deficiency is mostly found in people with a strict vegetarian diet. Dairy products, leafy vegetables, and certain fruits are good sources of riboflavin [35]. Including a variety of fruits and vegetables in a strictly vegetarian diet can help fight vitamin B2 deficiency.

iii) Niacin (Vitamin B3)

Niacin, niacinamide, and nicotinamide are three different forms of vitamin B3. Although niacin is only one type of vitamin B3, it is often used to denote the total vitamin B3. All three forms of vitamin B3 are converted to nicotinamide adenine dinucleotide (NAD) in the human body. NAD is involved in more reactions than any other vitamin-derived molecule [36]. It has anti-inflammatory properties, plays a central role in aerobic respiration, and maintains immunological homeostasis [33]. The deficiency of vitamin B3 in the human body causes pellagra disease. This disease is characterized by extreme weakness, diarrhea, dermatitis, and dementia [36]. Plant products are the primary source of niacin, while animal products are a source of nicotinamide. Under-utilized fruits like tamarind, soursop, custard apple, mangosteen, etc are good sources of vitamin B3 [9].

B. Ascorbic acid (Vitamin C)

Vitamin C is one of the essential water-soluble vitamins. It is present in the body in its reduced form as ascorbic acid. It helps maintain collagen and modulates neurotransmitter biosynthesis [37]. It is necessary to transform cholesterol to bile and enhance iron's availability and bioabsorption in the human body. The most common use of Vitamin C is to treat the common cold; however, this use of the vitamin is controversial [38]. A deficiency of Vitamin C in the body causes scurvy bleeding of gums, fatigue, impaired wound healing, and irregular bone growth [39]. It is widely found in fresh fruits like citrus fruits, kiwi, strawberries, gooseberries, broccoli, Brussel sprouts, green chillis etc. [40]. Many under-utilized fruits are an excellent source of Vitamin C.

Gooseberry, commonly known as Amla or Anola, are found in Indian subtropical regions like Uttar Pradesh, Tamil Nadu, Rajasthan, and Madhya Pradesh, popularly known as Indian gooseberry. It has therapeutic values and is used in Ayurveda and Unani medicines. It is sour and astringent in taste when flesh restricts its direct intake (Sonkar et al., 2020). The fruit is spherical and greenish or slightly yellowish; the flesh is hard, but the outer covering is smooth with six vertical furrows. The fruit is one of the richest sources of Vitamin C. [41]. The fruit juice treats various diseases like tuberculosis of the lungs, asthma, bronchitis, conjunctivitis, and glaucoma. Many studies have suggested that fruit extracts have protective abilities against heart, lungs, gastric lining, and kidney diseases [42].

III. PHYTOCHEMICAL COMPOSITION

The phytochemicals are the secondary metabolites produced by the plants, which are not nutritious but are beneficial for human health. They have antioxidant, anti-inflammatory, anti-cancer, and lipid profile altering capabilities, making them protective and preventive against a variety of diseases. Recent studies have shown that phytochemicals contribute more to human health than nutrition and vitamins. They play an important role in preventing many diseases like cancer, osteoporosis, cardiac disease, diabetes, and vision-related effects [43].

Phytochemicals in underutilized fruits, vegetables, and herbs help reduce cancer such as colon, stomach, lung, prostate, and breast. The antioxidant property of these chemicals reduces the interaction of carcinogens or oxidants with DNA, thereby decreasing carcinogenesis. They also reduce the spread of cancer by slowing the proliferation of cancer cells [43]. Many epidemiological studies have shown the role of underutilized fruits and vegetables in controlling diseases [43].

These phytochemicals are classified into several classes: phenols, terpenoids, alkaloids, carotenoids, phytosterols, etc. These are helpful to human health [43]. Some of the significant phytochemicals are discussed in the following section.

Fig. 2: Some under-utilized fruits of India.

Table 6: Some of the under-utilized fruits of India as a source of minerals.

Name of Fruits	Cadmium	Calcium	Chromium	Cobalt	Copper	Iron	Magnesium	Manganese	Molybdenum	Nickel	Phosphorus	Potassium	Selenium	Zinc
	←						mg	→					µg	mg
Bael fruit *(Aegle marmelos)*	0.027	47.95	0.002	0.419	0.15	0.23	34.1	0.1	0.819	0.042	37.29	409	0.72	0.14
Custard Apple (*Annona squamosa*)		28.2	0.003		0.19	0.42	38.47	0.15			40.81	278		0.22
Gooseberry (*Emblica officinalis*)		20.14	0.007		0.12	1.25	6.5	0.11	0.001	0.01	21.85	2.23		0.05
Jack fruit (*Artocarpus heterophyllus*)		35.03	0.005		0.19	0.36	31.84	0.35		0.005	23.02	279		0.17
Jambu fruits (*Syzygium samarangense*)		25.36	0.015		0.02	0.33	27.97	0.04		0.016	9.6	103		0.06
Karonda fruit (*Carissa carandas*)	0.002	10.81	0.002	0.001	0.71	0.87	24.45	0.24	0.006	0.01	32.62	351	1.57	0.25
Litchi (*Litchi chinensis*)		5.77	0.01		0.11	0.79	14.58	0.04		0.007	23.32	161	0.46	0.24
Mangosteen (*Garcinia mangostana*)	0.002	4.69	0.003	1.501	0.11	0.28	12	0.04	0.002	5.183	7.18	46.93		0.21
Manila tamarind (*Pithecellobium dulce*)		8.51			0.22	0.71	32.98	0.27			73.53	376		0.56
Musk melon (*Cucumis melon*)		9.8	0.004	0.001	0.03	0.18	11.62	0.04		0.006	17.28	206	0.88	0.09
Phalsa (*Grewia asiatica*)		153			0.24	2.01	76.92	0.47	0.003	0.006	23.65	362	3.53	0.48
Pummelo (*Citrus maxima*)	14.03	0.001			0.03	0.06	6.83	0.01	0.001		13.99	189		0.06
Rambutan (*Nephelium lappaceum*)		8.67	0.003		0.08	0.37	21.38	0.37			6.98	131		0.53
Sapota (*Achras sapota*)		17.87	0.01				16.19	0.08	0.001	0.029	22.26	280	0.39	0.18
Soursop (*Annona muricata*)		10.05	0.001				17.7	0.07			25.83	264		0.12
Star fruit (*Averrhoa carambola*)	0.852	4.97	0.023	0.002			11.53	0.06	0.01	0.028	11.67	159	0.56	0.24
Tamarind (*Tamarindus indica*)							82.73	0.52	0.07	0.032	113	836	2.05	0.58
Wood Apple (*Limonia acidissima*)		55.71	0.004	0.001	0.2	0.45	23.7	0.2		0.025	84.32	347	2.32	0.31
Zizyphus (*Zizyphus jujube*)		46.55	0.006			0.4	16.72	0.24		0.008	32.38	237	1.42	0.1

All the units are per 100g of the edible fruits.

Table 7: Some under-utilized fruits of India as a source of vitamins.

Name of Fruits	B1	B2	B3	B5	B6	B7	B9	C
	←			mg		→	µg	mg
Bael fruit (*Aegle marmelos*)	0.03	0.04	0.25	1.62	0.03	1.14	55.22	7.5
Custard Apple (*Annona squamosa*)	0.13	0.09	0.69	0.19	0.07	0.76	7.6	21.51
Gooseberry (*Emblica officinalis*)	0.01	0.03	0.12	0.35	0.27	1.42	7.86	252
Jack fruit (*Artocarpus heterophyllus*)	0.05	0.01	0.42	0.16	0.22	4	32.15	6.73
Jambu fruits (*Syzygium samarangense*)	0.02	0.02	0.14	0.31	0.03	2.57	7.63	16.47
Karonda fruit (*Carissa carandas*)	0.01	0.02	0.25	0.67	0.08	1.55	8.72	135
Litchi (*Litchi chinensis*)	0.02	0.06	0.23	0.19	0.07	2.8	15.69	33.82
Mangosteen (*Garcinia mangostana*)	0.01	0.01	0.58	0.15	0.18	0.81	13.52	26.33
Manila tamarind (*Pithecellobium dulce*)	0.18	0.14	0.4	0.18	0.04	0.22	4.24	55.78
Musk melon (*Cucumis melon*)	0.01	0.01	0.41	0.13	0.05	0.75	22.31	22.76
Palm fruit (*Borassus flabelifer*)	0.1		0.46	0.13	0.07	2.49	24.4	0.25
Phalsa (*Grewia asiatica*)	0.03	0.06	0.4	0.17	0.03	1.49	22.56	5.11
Pummelo (*Citrus maxima*)	0.06	0.02	0.23	0.05	0.04	1.81	13.44	48.89
Rambutan (*Nephelium lappaceum*)	0.11	0.01	0.26	0.14	0.04	0.64	7.35	65
Sapota (*Achras sapota*)	0.01	0.03	0.24	0.24	0.12	1.48	10.83	20.96
Soursop (*Annona muricata*)	0.03	0.04	0.85	0.12	0.03	0.23	6.09	59.54
Star fruit (*Averrhoa carambola*)	0.08	0.02	0.34	0.26	0.06	0.13	8.43	33.55
Tamarind (*Tamarindus indica*)	0.34	0.07	1.56	0.17	0.08	0.66	9.79	3.62
Wood Apple (*Limonia acidissima*)	0.04	0.01	0.55	0.22	0.17	1.65	6.51	22.17
Zizyphus (*Zizyphus jujube*)	0.01	0.02	0.33	0.14	0.11	2.22	5.99	60.93

All the units are per 100 g of edible fruits.

Phenolic compounds

The phenolic compounds are a diverse group of secondary metabolites with aromatic ring-bearing compounds and one or more hydroxyl groups. They are water-soluble compounds like phenolic acid, flavonoids, quinones, etc., and water-insoluble like tannins, lignin, etc. [44]. The phenolic compounds present in fruits and vegetables work as antioxidants and have biological properties like anti-inflammatory, anti-microbial, anti-tumor, anti-bacterial, etc. The antioxidants donate an electron to the free radicals and reduce oxidative stress [45]. Thus, a diet rich in polyphenols helps protect against diseases like cancer, autoimmune disease, Parkinson’s disease, etc. [46]. Fruits are a good source of antioxidants, including phenolic acid, flavonoids, anthocyanins, tannins. Studies have shown that polyphenols protect against many inflammation-mediated chronic diseases by interacting with proteins involved in cell signaling and gene expression [47]. Epidemiological studies have shown that anthocyanins are involved in the protection against type 2 diabetes in humans [48]. Flavonoids have anti-oxidant activity and can inhibit angiogenesis. Several flavonoid molecules have selective activity against cancerous cells over normal cells [47]. Some flavonoids like breviscapine regulate the protein expression regarding apoptosis and protect the brain against ischaemic damage [44]. Fruits like wood apple, tamarind, zizyphus have high polyphenols content. The zizyphus or jujube (*Zizyphus jujube* Mill.) fruit grown mostly in Europe, southern and eastern Asia, and Australia belongs to the Rhamnaceous family [49]. The unripe fruits are oval, smooth, and green, and on ripening, they turn red or brown and are wrinkled, looking like small dates. The fruits are edible, have high nutritional value, and are a great source of polyphenols. Many studies have reported the high antioxidant activity in the peel, pulp, and zizyphus fruits' seed [50]. This antioxidant activity is due to the high polyphenol content of the fruit. 100 g of the edible jujube fruit contains about 131 mg of total polyphenols [9]. Peel is the richest among the other parts of the fruits in the total polyphenols. Protocatechuic acid is the predominant phenolic acid in the zizyphus fruit followed by gallic acid, chlorogenic acid, and caffeic acid [49]. Many studies have reported the therapeutic potential of zizyphus fruits against inflammatory diseases. The fruit contains triterpene acids which play a significant role against these diseases [51]. Wood Apple is also a good source of polyphenols like alkaloids, flavonoids, phenols, terpenoids, tannins, fats, sterols, saponins, etc. It is an under-utilized fruit used by tribals and rural populations as raw fruit and treats various diseases. The fruit extract has antimicrobial and antifungal properties and is used to cure dysentery, hiccups, soar throat, etc. It is considered a good source of polyphenols, and 100 g of the fruit pulp contains 411 mg of the total polyphenols. Tamarind is an under-utilized fruit used in many food preparations in India. It is rich in many polyphenols. The antioxidant activity of the fruit is higher than avocado, jackfruit, mango, and longan fruit [52]. The fruit also has anti-inflammatory, anti-diabetic, and anti-cancerous properties and acts against cardiovascular diseases [52], [53], [54]. Phalsa fruit is rich in polyphenols with total polyphenol content of

1900 mM GAE /g of 100 g of fruit. The fruit is rich in antioxidant activity.

Carotenoids

Carotenoids are plant pigments that provide color and help in harvesting sunlight for photosynthesis and fall under the terpenoids class. It contributes to the yellow, orange, and red colors of fruits and vegetables [55]. Carotenoids are not synthesized in humans and are required in the diet. They have antioxidant properties and protect against cardiovascular diseases and cancer (Rodriguez-Concepcion et al., 2018). They also increase immunity and bone health. Some carotenoids like β-carotene, α-carotene, and β-cryptoxanthin are precursors of vitamin A biosynthesis [57]. Lutein is a carotenoid pigment that provides yellow or orange color to common food like carrot, corn, red/orange pepper, fish, and egg yolk. It improves cognitive function, visual health, and skin health in humans. It has anti-inflammatory and antioxidant properties and acts as a neuroprotective agent. Many studies have reported increased intake of lutein can protect against age-related muscle degeneration [58]. Zeaxanthin is a carotenoid pigment belonging to the xanthophyll family found in fruits and vegetables. It has antioxidant, antiparasitic, anthelmintic activity and protects against neurological, skin and eye disorders [59]. Table 8 lists the phytochemical composition of some under-utilized fruits of India [9]. Phalsa (*Grewia asiatica* L.) is a fruit berry of the tropical regions of South Asia, typically India and Pakistan. It is a rich source of many polyphenols and is used in the treatment of various medical conditions like diarrhea, jaundice, upset stomach, rheumatism, diabetes, intestinal infections, cough, fever, wound healing, skin diseases, and osteoporosis [60], [61]. The fruit is rich in carotenoids, and it contains 157 mg lutein and 3.11 mg zeaxanthin per 100 g of edible fruit. It The berry is also rich in essential fatty acids.

Phytosterols

Phytosterols are plant-derived micronutrients and are structurally and functionally analogous to cholesterols [62]. Unlike cholesterols, the human body cannot synthesize phytosterols and obtain them only through diet. Oils, fruits, vegetables, nuts, legumes, whole grains, tubers, and sunflower seeds are different sources of phytosterols [63] The saturated and unsaturated phytosterols are called sterols and stanols, respectively. Campesterol, β sitosterols, and stigmasterol are the three most common sterols found in the human diet [64]. They all contain the core structural skeleton of cholesterol with a different side chain. Stanols only form 10 % of the dietary phytosterols. Phytosterols and their derivatives have various pharmacological properties. They can reduce lipoprotein disorders, insulin resistance, and β-cells dysfunction, attenuate adipose inflammatory signaling, enhance mitochondrial ATP content, and decrease oxidative stress, as well as ameliorate gut microbiota dysbiosis and barrier dysfunction [63], [65], [66] Sapota (*Achras sapota*), also known as royen fruit belongs to the Sapotaceae family. The fruits are round or elongated, nutritious, and delicious [67]. The fruits are rich in vitamins, minerals, proteins, ascorbic acid, polyphenols, and carotenoids [68]. The fruits have high antioxidant activity and are used to treat many diseases. The decoction of the fruit is used against diarrhea. An infusion of fruits and flowers of Sapota relieves pulmonary complaints [69]. The fruit is rich in carotenoids containing 72.8 mg of β-Sitosterol per 100 g of the edible portion of the fruit [9]. *Citrus maxima*, commonly known as pomelo, belongs to the Rutaceae family. It is one of the largest underutilized citrus fruits of the country. The fruit is used as a remedy against sore throat, insomnia, fever, and cardiac diseases. The fruit has antioxidant, anti-inflammatory, and anti-diabetic properties. The fruit has a bitter and astringent taste [70] It is rich in carotenoids like campesterol and β-sitosterol.

Table 8: The phytochemical composition of some of the under-utilized fruits of India.

Name of Fruits	Total Polyphenols (mg)	Carotenoids (mg)			Phytosterols (mg)			Total Saponin (g)
		Lutein	*Zeaxanthin*	*β-Carotene*	*Campesterol*	*Stigmasterol*	*β-Sitosterol*	
Bael fruit (*Aegle marmelos*)	21.36	36.12	2.2	2.5	0.3	0.41	3.39	
Custard Apple (*Annona squamosa*)	13.91	12.45	1.8		0.65	2.19	3.81	
Gooseberry (*Emblica officinalis*)	1031	38.7	2.86	1.58	0.23	0.23	11.5	0.4
Jack fruit (*Artocarpus heterophyllus*)	53.74	19.3	2.42	23.53	1.04	19.21	34.84	
Jambu fruits (*Syzygium samarangense*)	68.47	18.49	5.68	1.55	0.76	0.14	25.45	1.55
Karonda fruit (*Carissa carandas*)	10.65	6.12	1.14	15.64	0.72	0.48	4.92	
Litchi (*Litchi chinensis*)	124	27.33	1.61	1.47	5.3	1.43	10.67	1.04
Mangosteen (*Garcinia mangostana*)		16.81	5.4	1.8	0.67	0.37	4.32	
Manila tamarind (*Pithecellobium*)	10.35	36.5	10.5	2.2	0.29	0.97	16.43	
Musk melon (*Cucumis melon*)	5.33	20.17	2.52	117	0.15	0.38	2.74	
Palm fruit (*Borassus flabelifer*)	28.36	5.8	1.5					

Phalsa (*Grewia asiatica*)	57.25	157	3.11	1.71	2.28	1.48	24.97	0.63
Pummelo (*Citrus maxima*)	25.35	22.5	5.9	1.55	34.39	0.92	23.7	88.76
Rambutan (*Nephelium lappaceum*)	11.21	16.8	2.5	2.9				
Sapota (*Achras sapota*)	17.27	22.6	2.09	80.7	1.48	1.48	72.8	
Soursop (*Annona muricata*)	16.54	29.8	5.3	2.2	4.71	1.12	10.88	
Star fruit (*Averrhoa carambola*)	21.69	26.8	2.6	1.4	0.96	0.41	41.65	
Tamarind (*Tamarindus indica*)	183	28.4	11.61	1.54	4.3	0.54	43.29	
Wood Apple (*Limonia acidissima*)	411	11	2.57	3.81	3.86	4.63	20.55	0.28
Zizyphus (*Zizyphus jujube*)	131	10.7	1.6	1.5	0.63	0.39	10.09	

All the units are per 100 g of edible fruit.

IV. CONCLUSION

The underutilized fruit of India are rich in major and minor nutrients. Proper exploitation of these fruits can help in solving the vitamin and mineral deficiency in the Indian population. They can protect against several deficiency disorders. Compared to the conventional fruits the underutilized fruits are cheaper. These fruits are rich in phytochemicals and have many medicinal properties. They are used by the rural population for curing many diseases. Development of technologies for the post-harvest processing of these fruits can also help in developing employment for the rural population.

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