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Nutritional Bioactive Compounds and Health Benefits of Fresh and Processed Cucumber (*Cucumis Sativus* L.)

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Abstract

Gherkin (*Cucumis sativus* L.) generally known as commercial cucumber, is native to the region of Asia, and is now widely cultivated in many other parts of the world to be sold fresh and for pickle production. Cucumber is a rich source of valuable nutrients and bio active compounds and is used not only as food but also in therapeutic medicine and cosmetology. Cucumber is considered as a vegetable crop and is rich in polyphenolics and cucurbitacins, that are known to possess multiple biological activities such as antioxidant, anti-carcinogenic, anti-hyaluronidase, anti-elastase, anti-inflammatory, anti-hyperglycemic, diuretic, amylolytic, antimicrobial, and analgesic effects. Fruits that are preserved by dipping in a solution of salt or vinegar that undergo a fermentation process are known as pickles. Since, pickling of gherkins enhances the flavor, texture, and nutritional aspects, it is also very popular for its nutritive and health-promoting potential; especially against diabetes complications and cardiovascular disorders due to the presence of monounsaturated fats and other valuable minor components such as phenolics etc. The variety, geographic location of production, harvest time, and the processing techniques practiced are some of the factors shown to influence the composition of cucumber. This review focuses comprehensively on the nutrients and high-value bio active compound profile as well as medicinal and functional aspects of fresh and processed cucumber. Multiple benefits associated with the phytochemical and nutritional composition of this food commodity are also discussed in the following sections.

Keywords: Cucumber; Gherkin; Cucurbitacins; Phytochemicals; Antioxidants; Health benefits.

1. Introduction

Cucumber belongs to family Cucurbitaceae, is comprised of 118 genera and 825 species [1-3]. Though they have an Asian origin, members of this family are largely scattered over both in tropical and subtropical regions of the world. One of the most demanded cucurbits due its nutritional values, health benefits and diverse production is cucumber [3-6]. Cucumbers are widely cultivated in Europe and the annual production shows in the region of 26.7% of the total vegetable production [2, 7, 8]. Even though Cucumber is a rich source of important nutrients and bioactive compounds, it has been used not only as food but also in therapeutic medicine and beauty culture applications since ancient times [5, 9, 10].

Also cucumber is rich in moisture content and very low in calories [11]. Cucumber considered as vegetable crop is rich in polyphenolics and other phytochemicals [12] that are known to possess multiple biological activities such as antioxidant, ant carcinogenic, anti-hyaluronidase, anti-elastase, hypolipidemic, anti-inflammatory, anti-hyperglycemic, diuretic, amylolytic, antimicrobial, and analgesic activities [9, 11, 13-15].

These fruits are preserved by dipping it in a solution of salt or vinegar are known as pickles that undergo a fermentation process [3, 16, 17]. Since, the gherkin pickling enhances the flavor, texture, and nutritional aspects, it has also gained popularity for its nutritive and health-promoting potential; especially against diabetes complications, cardiovascular disorders due to the presence of monounsaturated fats and other valuable minor components such as phenolics etc.[9, 11, 15, 16]. Further, cucumber consumption is recommended for hypertension, treating Alzheimer's disease, prevention of various skin problems, including swelling below the eyes, sunburn and are assumed to increase cooling, healing, soothing, emollient and anti-itching effects to irritated skin.

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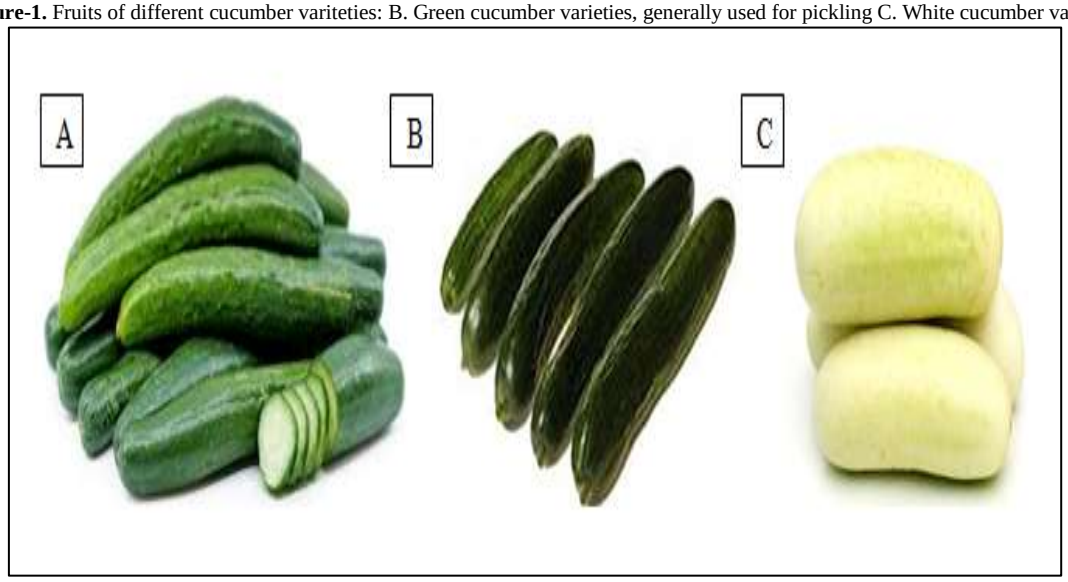
Figure-1. Fruits of different cucumber variteties: B. Green cucumber varieties, generally used for pickling C. White cucumber variety



Cucumber fruit can be pendulous, globose to tubular berry and can extend to over 30 cm in length. Usually, the fruit is slightly rounded, sparsely tuberculate, or warty. When it gets younger, the fruit becomes a smooth and glabrous shape, the peel is normally green, but in some cultivars (Figure 1) white, yellow or brown colors are apparent while the flesh is pale green to white in color [18]. The cultivar, area of production, harvest time, and the processing techniques employed are some of the factors shown to influence the composition of cucumber. This review focuses comprehensively on the nutrients and high value bioactive compound profile as well as medicinal and functional aspects of fresh and processed Cucumber. Multiple benefits associated with the phytochemical and nutritional composition of this food commodity are also discussed in the following sections.

2. Nutritional Profile

Chemical composition represents an important factor with direct influence on the quality of gherkins. Gherkin (*Cucumis sativus* L.) has similar nutrient values as cucumber [3]. The nutritional composition of a 100g portion of cucumber includes most of its weight in water with proteins, fat and carbohydrates as primary metabolites and also dietary fiber that is important for the digestive system [2, 12, 18-22]. The nutritional benefits of cucumber in terms of micronutrient contributions are notable. Cucumber fruit generally contains water (95%) and minute amounts of protein (0.6%), lipids (0.1%) and carbohydrates (2.2%) [2].

The Carbohydrate content of food samples is calculated as the difference between 100 and the total percent of moisture, protein, fat, and ash [19]. According to USDA (United States Department of Agriculture) database, carbohydrates account for 2.16g per 100g of the edible portion of raw cucumber and it's further comprised of total dietary fibre (0.7g), total sugars (1.38g), glucose (0.63g), fructose (0.75g) and starch (0.08g) [22]. Moreover, it is comprised of fluorine (1.3mg), selenium (0.1mg); vitamin C (3.2mg), thiamin (0.031mg), riboflavin (0.025mg), niacin (0.037mg), pantothenic acid (0.240mg), vitamin B-6 (0.051mg), folate (14µg), γ-tocopherol (0.02mg), vitamin K (72mg), alpha-tocopherol (0.03mg), vitamin A (4µgRAE), vitamin A (72IU), choline (5.7mg), betaine (0.1mg), beta-carotene (31µg), alpha-carotene (8µg), beta cryptoxanthin (18µg), lutein + zeaxanthin (16µg) and total saturated fatty acids 0.013 g per 100g of the edible portion of raw cucumber [18, 22].

The proximate values of the cucumber fruits grown in different countries are tabulated in Table 1 with the references. The average moisture content of cucumber studied by Abulude, *et al.* [19] have reported as 73.29%. Nevertheless, all the other samples have reported moisture availability of cucumber nearly within 95% to 96%. Moreover, in the aforementioned study, they have found that moisture content of the endocarp of cucumber fruit is 95.26% [19]. This might be due to the morphological variations such as the presence of a hard pericarp. The cultivar, area of production and harvest time may be the reasons behind slight variations in the nutritional composition. Accordingly, a conclusion can be drawn that composition varies depending on the place where it has grown. In recent studies, [20, 21] have explained that even though equal processing conditions are given in the brine fermentation of different gherkin varieties, firmness and quality of the final products have correlated with the initial moisture and mineral composition of the fresh fruits [20, 21].

Cucumber contains some essential vitamins and antioxidants which has an effect on human health [2, 13, 15]. The fresh cucumber supplies thiamine, vitamin C, niacin, phosphorus, iron, calcium and other nutritional factors [12]. Most vegetables contain substantial amounts of minerals, particularly calcium, iron, and potassium. But mineral content is not an indicator of nutritive value as the presence of interfering substances (ex: oxalic or phytic acid) can hinder bioavailability of these micronutrients. Among the minerals, cucumber fruit is rich in calcium, potassium and sodium compared to the availability of copper, manganese and iron (Table 2).

Potassium is very mobile in the plant. This mobility and the participation of K in activating numerous important enzyme reactions are significant properties of this element. Potassium has been given credit for several important roles in plant nutrition linked with the quality of production. Fiber includes insoluble fiber (lignin, cellulose, and hemicelluloses) and soluble fiber (pectins, β-glucans, galactomannan gums, and a large range of non-digestible oligosaccharides including inulin) [23]. Dietary fiber as a class of compounds includes a mixture of plant

carbohydrate polymers, both oligosaccharides, and polysaccharides, ex: cellulose, hemicelluloses, pectic substances, gums, resistant starch and inulin, that may be associated with lignin and other non-carbohydrate components such as polyphenols, waxes, saponins, phytates, and resistant protein [16].

Manganese is recognized for its significance in bone metabolism and is critical in enzyme reactions and the continuance of normal nerve and brain functions [19]. Mn deficiency is rare but can impair the brain, glucose sensitivity, reproduction, bone, and cartilage development [24, 25]. The mineral Zinc supports the health of the immune system, normal synthesis of protein and the health of reproductive organs. The scarcity of Zn negatively influences physical growth, nerve and immune functions, particularly in infants [19, 26]. Cu is required for blood, nerves, joints, heart, skin, liver, and functions in immune systems. Copper is also critical for the absorption and utilization of both Zn and Fe [27]. The inability to produce important antioxidant enzymes and a shortage of red blood cells has been linked to Cu deficiency.

Table-1. Nutrition composition of *Cucumis sativus* fruit with references

Method	Description	Proximate composition							Country	Reference
		Moisture	Protein	Fat	Carbs	Fiber	Ash	Energy/KJ		
AOAC 1990 and Pearson method 1976	Grams per100g Mean value of edible fruit	73.29	1.91	0.23	4.37	20.36	1.31	21.33	Nigeria	Abulude, *et al.* [19]
	Grams per100g of endo carp	95.26	0.22	0.02	ND	4.48	0.05	1.06	Nigeria	
AOAC 2000 method and Pearson method 1976	Homogenate sample, As a percentage	94.20	3.01	0.55	0.28	1.02	0.94	NM	Nigeria	Uzuazokaro, *et al.* [12]
AOAC 2000 methods	Vlasset variety, 100g of the fresh fruit	96.30	0.78	0.44	0.54	1.54	0.40	NM	Sri Lanka	Uthpala and Marapana [21]
AOAC 2000 methods	Ajax variety, 100g of the fresh fruit	95.54	1.12	0.68	0.48	1.37	0.81	NM	Sri Lanka	Uthpala and Marapana [21]
NM	Grams per 100g of the fresh fruit	95.00	0.6	0.1	2.2	NM	NM	NM	Greece	Sotiroudis, *et al.* [2]
AOAC methods	Raw cucumber fruit per 100 g edible portion	96.73	0.59	0.16	2.16	0.7	0.36	12	USA	Lim [18], Department of Agriculture [22]

NM - Not mentioned

Table-2. Mineral composition of the cucumber fruit with references

Description	Mineral									Methods	Reference
	Mg	Zn	Fe	Ca	K	Na	Mn	Cu	Pb		
Mean value of edible fruit, mg per kg	659.3	17.7	128	613.7	656.0	700.0	18	16	ND	Flame photometer and AAS	Abulude, *et al.* [19]
Raw endo carp of edible fruit, mg per kg	629	15	113	551	701	636	12	4.1	ND		
Vlasset variety, 100g of the fresh fruit	9.00	14.09	-	10.62	118.85	13.46	NM	NM	NM	AAS	Uthpala and Marapana [21]
Ajax variety, 100g of the fresh fruit	16.60	14.69	-	7.76	194.0	10.47	NM	NM	NM		
Raw cucumber fruit, mg per 100 g edible portion	12.00	0.17	0.22	14	136	2	0.073	0.0711	NM	-	Lim [18]

Note: Mean values of the mineral compositions of cucumber fruits. ND: Not Detected, NM- Not mentioned

3. Phytochemicals

Notwithstanding the commercial value of cucumber and its therapeutic interest, there are several studies that have been carried out relevant to its chemical consistency and its bioactivity. Phytochemicals are secondary metabolites produced by plants. These products are biologically active, naturally occurring substances in the plant, furnishing health benefits for humans than macronutrients and micronutrients [17]. These studies mainly concern the aroma constituents of fresh or fermented cucumber fruits [7, 8] or their fatty acid composition [11, 28]. Further, the total antioxidant activity and total phenolic content of fresh cucumbers have already been determined [2, 12, 29] and studies on polyphenolic content and antioxidant activity in various cucumber fruit tissues have been carried out.

Table-3. Quantitative phytochemical constituents of the homogenate of Cucumis sativus fruit

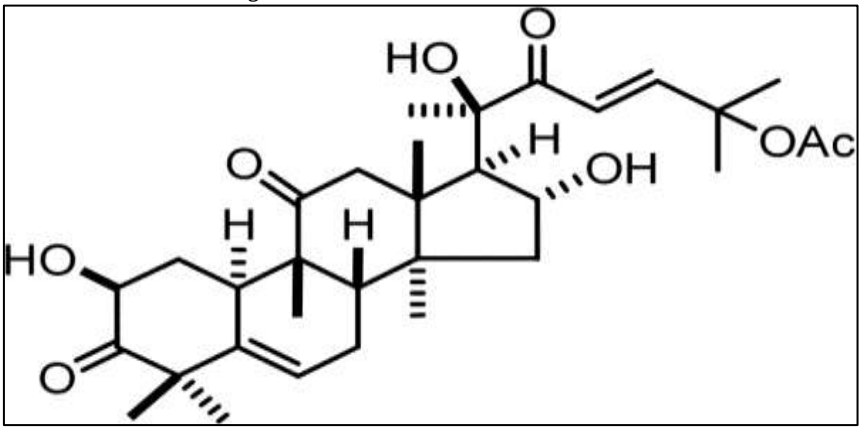
Phytochemicals	**Composition (mg/g)** [mean value] [12]	**Method**
Tannins	1.26	Spectrophotometric determination method [30]
Polyphenols	8.51	Spectrophotometric method [31]
Phenols	7.72	spectrophotometric method [31]
Cyanogenic glycosides	0.21	Alkaline picrate method [32, 33]
Anthocyanins	1.21	pH differentiation method [34]
Glycosides	32.23	Spectrophotometric method of by Quasheeh [35], Trease and Evans [36]
Reducing sugars	574.36	Folin and Wu method [37]
Saponins	2.01	Spectrometric determination method [38]
Alkaloids	2.22	Harborne method [34]
Flavonoids	2.14	Ferric chloride colorimetric method [39]
Terpenoids	26.27	Oxidation method of Harborne [34]
Steroids	11.69	Method described by Edeoga and others [40]
Resins	50.70	UV absorption method of Harborne [34]
Chlorophyll a	4.49	Harborne [34] method
Chlorophyll b	12.09	Harborne [34] method

Nigerian scientists [16] have conducted a phytochemical screening on cucumber homogenate samples and they have found that relatively higher amounts of steroids, terpenoids, glycosides, and resins are present in cucumber while moderate amounts of saponins, alkaloids, and flavonoids have been reported. Quantitative amounts of the phytochemicals available in fruit homogenate are tabulated in table 3 with the tested method conducted by Uzuazokaro and others. The bio-active compound of reducing sugars found to be in the highest amount (574.4mg/g) relatively compared to other phytochemicals followed by resins (50.7 mg/g), glycosides (32.2 mg/g), terpinoids (26.3 mg/g), chlorophyll B (12 mg/g) and cyanogenic glycosides (0.21 mg/g) are the lowest available phytochemicals. Sotiroudis, *et al.* [2] have revealed that there are 21 volatile chemicals available through GCMS (gas chromatography-mass spectrometry) analysis in three different cultivars grown in Greece [2]. The major components from the above analysis were found to be: Z-6-nonenol, E-2-nonenal, E,Z2,6-nonadienal, E-2-nonenal, Z-3-nonenol, 3-nonenal, pentadecanal, 9,12,15-octadecatrienal and 9,17-octadecadienal [2, 18].

The availability of cucurbitacins, is the characteristic feature of the family Cucurbitaceae. Cucurbitacins (Figure 2) are basically triterpenoid substances responsible for their bitterness and toxicity [11, 41]. Structurally, they are tetracyclic terpenes with steroid and have a tetracyclic cucurbitane nucleus skeleton, namely, 9β-methyl-19-nor lanosta-5-enea, which is arbitrarily divided into twelve categories [11]. Due to the effects of the enzyme elaterase, cucurbitacins are hydrolyzed to its non-bitter form when cucumber fruits get matured [42]. Further, the oral treatment of the pectin extracted from the cucumber fruits has exhibited notable hypolipidemic action in animals [43].

Researchers have found that most of the volatile compounds available in the fresh fruit remained unchanged during fermentation [8]. However, the potential of disrupted cucumber tissue to produce (*E*, *Z*)-2,6-nonadienal and 2-nonenal reduced during fermentation is prominent which gives fresh cucumber odor. Besides, linalool levels had improved with the time of fermentation and it can achieve an odor threshold during the first 10 days of brine fermentation [8]. Uronic acid (UA) is related to the cell wall component pectin. D-galacturonic acid determines the pectin content present in the fruits [16]. UA content can be determined after acid hydrolysis of the sample and reacting with carbozol directly measured by spectrophotometric methods. Uthpala and Marapana [21] have found that irrespective of the variety, UA content of brine-fermented pickles have decreased as the pectin content decreases with the time [16, 21]. Scriven and Meloan [44] have found that natural insects show repellent ability due to presence of (E, Z)-2,6-nonadien-l-al and (E)-2-nonen-l-al compounds in crushed cucumber [44].

Figure-2. Chemical structure of cucurbitacin B



4. Health Benefits

Cucumber is remarkably helpful for overall health; it could relieve thirst as it is rich in moisture and vital nutrients that are necessary for the human body [45]. Cucurbitacin B (Figure 2) is a natural substance that is discovered profusely in cucumbers, and it exerts anti-cancer potential primarily through apoptosis-induction in diverse human cancer cells [46]. Also Gao, *et al.* [46] have found that cucurbitacin B encompasses potent chemo-preventive activity against human prostate cancer [46]. Cucumber peel is a good source of dietary fiber that helps reduce constipation and offers some assurance upon colon cancers by eliminating toxic aggregates from the abdomen.

The disease of diabetes mellitus is increasing fast and symbolizes a vital lifestyle and fitness issue in society. This disease and its associated complexities, comprising of nerve dysfunction, kidney failure, and heart failure, have grown as significant reasons for morbidity and risk of death [47]. Cucumbers are contained with unique antioxidants in moderate ratios such as ß-carotene and α-carotene, vitamin-C, vitamin-A, zeaxanthin and lutein. These compounds help act as protecting collectors against oxygen-derived free radicals. Oxidative stress and carbonyl stress play as crucial functions in the progression of diabetes and its associated difficulties over developing free radical generation and weakening antioxidant defense systems [48, 49]. Various chemical and natural compounds have been proposed for mitigating such complications linked to diabetes [4, 5]. Accordingly, Heidari, *et al.* [49] have found that cucumber has protective impacts on diabetes developments and is recognized as a reliable food for lowering the oxidative stress and carbonyl stress apparent in the disease of diabetes [49].

Also, cucumber juice is extremely good for hair, skin, and nails. Skin generates free radicals due to repeated sun exposure, which leads to oxidative stresses and inflammatory responses in the dermal layer of the connective tissues ending aging and harm to cell membranes and biological molecules [15, 50, 51]. Hyaluronic acid and elastin are accountable for the elasticity of connective tissue and it reduces clearly during aging [52]. Researchers have found that cucumber is a rich source of ascorbic acid and has the potential of anti-hyaluronidase and anti-elastase ability which justifies the use of cucumber as a possible anti-wrinkle agent [15]. Utilization of cucumber for various skin problems, including swelling below the eyes and sunburn are assumed to increase cooling, healing, soothing, emollient, lenitive, anti-itching effect of irritated skin, and further cosmetic effects [11, 15]. Cucumber is a rich source of Silicon which is beneficial for healthy connective tissues, ligaments, cartilages and etc. [18, 53].

Naturally fermented sour pickled cucumbers belong to the commodities preserved with salt and lactic acid. Fermented cucumbers are microbiologically safe, nutritious, have appealing sensory attributes, and can conveniently be stored for long periods without refrigeration [54]. Moreover, these pickles are recognized for their probiotic potential. Hence fermented cucumber pickles are health wise beneficial due to the availability of probiotic lactic acid bacteria (LAB) in the fermented cucumbers [55]. Lacto fermented cucumber is comprised of helpful bacteria that hinder the growth of unhealthy microorganisms in the intestines [3].

Further, cucumbers have moderate diuretic potential, which is reasonably attributed to their free-water, potassium and low sodium content. This helps in checking weight gain and high blood pressure. High potassium in cucumber helps to lower blood pressure. They are rich in Vitamin-K which plays vital role in the bone mass developing activity [19]. Moreover, it is used in the treatment of Alzheimer's disease patients by limiting neuronal damage in their brain. Moreover, cucumber consumption is recommended for hypertension, treating Alzheimer's disease [56, 57], prevention of various skin problems (swelling below the eyes, sunburn) and are assumed to increase cooling, healing, soothing, emollient, lenitive and for anti-itching effect of irritated skin [11].

5. Conclusion

Cucumber is a rich source of important nutrients and bioactive compounds and is consumed as a healthy food which is further used in pharmacological activities, beauty care, and insecticidal purposes. Cucumbers are recognized as vegetables with multiple biological activities including, antioxidant, anti-carcinogenic, anti-hyaluronidase, anti-elastase, anti-inflammatory, anti-hyperglycemic, diuretic, amylolytic, antimicrobial, and analgesic effects.

Health benefits of fresh cucumbers include prevention of diabetes mellitus, hypertension, treating Alzheimer's disease, preventing cancer and anti-aging, while fermented cucumber is rich in fiber and probiotics. The nutritional, phytochemical and health benefits detailed throughout this article will serve to maximize the utilized health interests of this unique vegetable.

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