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The potential antidiabetic properties of Liang (*Gnetum gnemon* var.*tenerum*) leaves

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Abstract

Diabetes mellitus (DM) is a serious global health problem. Type 2 diabetes mellitus (T2DM) is insulin resistance and islet β-cell impairment. Oral medications or injection agents can have negative effects. Literature reviews showed that chlorophyllin inhibit gluconeogenesis and increase glucose uptake by the peripheral muscles. Scientific data also revealed that glutamine, alanine, arginine, and leucine increase insulin secretion by stimulating the changing of glucose to pyruvate and enhancing the TCA cycle to increase activate membrane depolarization. Fiber in either the insoluble or soluble form can reduce blood sugar. Soluble fibers reduce blood sugar by interfering with carbohydrate and fat absorption. Natural products containing high protein and fiber as well as chlorophyllin derivatives have been investigated extensively for anti-diabetes properties. The leaves of Liang contain high protein, fiber, and chlorophyll; therefore, the leaves of this plant must have good potential to be an alternative natural antidiabetic agent.

Keywords: Liang leaves; diabetes; amino acids; chlorophyllin; fiber.

Practical Application: Natural product for blood sugar controlling is focusing and more intensively research due to high market value. *Gnetum gnemon* leaves are regularly consumed and are an interesting candidate for use in diabetic management due to their high in protein, chlorophyll and fiber contents.

1 Introduction

In 2021, there were estimated 422 million diabetes patients globally (World Health Organization, 2021), and this number is forecast to reach 783 million by 2045 (International Diabetes Federation, 2021). The pathogenesis of diabetes mellitus (DM) is heterogeneous, but the disease is mainly due to inadequate insulin from either low secretion from beta cell (pancreases) or cell organelle could not use insulin effectively (Sapra & Bhandari, 2021) or both. DM is the 7th leading cause of death globally (Centers for Disease Control & Prevention, 2020). There are many types of DM but the majority of cases are one of three main types, type 1, type 2 and gestational diabetes, with type 2 accounting for approximately 90% of all cases (International Diabetes Federation, 2015). The main pathogenesis of type 2 DM is insulin resistance and islet β-cell function impairment (Goyal & Jialal, 2021). The main purpose of management, directed at either prevention or treatment, is to minimize insulin resistance and to preserve the beta cell function. The most important strategy is based on a diet that does not cause beta cell fatigue such as a diet that does not cause either insulin surges or insulin resistance. Such a diet is based on complex carbohydrates or low glycemic index food, and is the mainstay for all DM patients. Even though antidiabetic medications are indicated for many patients, most of them are associated with some adverse effects (Daramas et al., 2008), and thus there is still a need for effective antidiabetic agents without untoward side effects. Due to this ongoing need, in recent years there has been increased research into natural foods with antidiabetic properties.

There are three main compounds involving antidiabetic activity including chlorophyllin, some amino acids or protein and fiber. Chlorophyllin, a semi-synthetic chlorophyll compound has been reported to show similar effect to metformin in increasing cellular glucose uptake and inhibition of gluconeogenesis (Rena et al., 2017). The effect on blood sugar and lipids of semi-synthetic chlorophyll or chlorophyllin in streptozotocin-induced diabetic mice was investigated by Abani et al. (2016) who reported that, with intraperitoneal glucose loading, chlorophyllin produced similar blood glucose clearance to that of biguanide. Certain amino acids, notably leucine, arginine, alanine, and glutamine as well as protein hydrolysate can enhance insulin function by stimulating the conversion of glucose to pyruvate. Stimulation of the Krebs cycle causes the cellular production of energy. A benefit of taking leucine and arginine on the insulin secretion *in vivo* test has been reported (Newsholme et al., 2006). A clinical assessment on the effect of protein hydrolysate on type 2 diabetic patients found a threefold increment in insulin secretion compared with carbohydrate alone (Newsholme et al., 2006). In addition, dietary fiber has been found to reduce dietary sugar absorption into the bloodstream (Lattimer & Haub, 2010). When taken orally, plant fibers can lower blood glucose by mixing or diluting macronutrients and reducing

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contact with digestive enzymes. The study in rats found that fiber lowers postprandial glucose without changes of mucosal thickness or crypt anatomy thus other mechanism should be sought (Schwartz & Levine, 1980) such as bowel transit time. Fiber is known to increase intraluminal bulk thus decreases transit time that may decrease contact time of luminal content. Other possible mechanisms are the gut microbiota growth and their metabolites (Howarth et al., 2001) and colonic distension leading to more incretin secretion (Carolyn & Bo, 2011) glucose, all of which reduce the postprandial plasma glucose. Therefore, natural products, particularly products containing compounds such as chlorophyllin, fiber and certain amino acids such as glutamine, alanine, arginine, and leucine with potential anti-hyperglycemic properties, are interesting options for research into diabetes medications. Liang leaves have the fore mentioned factors and the potential antidiabetic properties are reviewed. This manuscript aims to intensive review about possibility of using Liang leaf for alternative anti-diabetic drug production and recommended Liang dishes for regular consumption.

2 Proximate composition

100 g of fresh leave of Liang (G. *gnemon* var. *gnemon*), a type of tree, provides 57 kcal with various nutritional values as shown in Table 1, while G. *gnemon* var. *tenerum,* a shrub found in Thailand contains less fat but higher fiber at around 28.77% by wet weight. Since there is no scientific data indicating antidiabetic property of these plants (both variety of *gnemon* and *tenerum,* therefore it is hypothesized that the plant leaf particularly *ternerum* variety should provide more diabetes-relevant activity compared to var. *gnemon.*

Based on data showed in Table 1, the *Gnetum* leaves stand out for their high protein and dietary fiber content from 4.1-4.2 g/100 g fresh weight (FW) and from 4.7-6.5 g/100 g fresh weight (FW), respectively, while their fat content is rather low. Those mentioned values agreed with the group of high protein vegetables such as pea, parsley, spinach, chard (Opazo-Navarrete et al., 2021). In addition, it was found that the leaves are rich source of copper, vitamin K and A with 0.85-12.1 ppm or 166.67-94.45% DV, 332.8 µg and 627.2 µg or 416% and 78% DV, respectively. As well-known leafy that green vegetables are an important source of vitamins, mineral and fiber which can offer numerous of health benefits (Morris et al., 2018). Actually, kale and green collard are appointed to be a great source of vitamin K, A and C (Weber, 2001). Low dietary vitamin K (< 70 µg/day) intake was associated with low bone mineral density (BMD) with an increased risk of hip fracture in women (Booth et al., 2000). In addition, with low carbohydrate, fat, and energy but high protein, this plant leaves are highly recommended for on diet and controlled-weight people as well as anemia disease due to Thalassemia and its carrier traits. From recent data, *Gnetum* leaves should offer an abundance of health benefits due to their powerful compounds. Therefore, having enough of *Gnetum* leaves should help reduce risk of obesity, heart disease, high blood pressure and mental decline. However, plant variety, location, maturity and post-harvest handling etc., may need to concern because all factors have a significant effect on their nutrition values and some specific compounds.

3 Gnetum gnemon

The *Gnetum* species belongs to the Gnetophyta division, a small group of gymnospermous vascular plants, with about 30 species

Table 1. Nutritional values of Liang leaves of *gnemon* and *tenerum* varieties.

Proximate composition	Sample			
	Gnetum gnemon var. *gnemon**		*Gnetum gnemon* var. *tenerum***	
	Amount	%DV	Amount	%DV
Water	81.7 g	N/D	84.0 g	N/D
Energy	57 kcal	N/D	58 kcal	N/D
Protein	4.2 g	8.40%	4.1 g	8.20%
Total fat	1.5 g	4.29%	0.33 g	0.94%
Ash	1.3 g	N/D	1.0 g	N/D
Carbohydrate	6.6 g	5.08%	9.6 g	7.39%
Crude fiber	4.7 g	N/D	6.5 g	N/D
Mineral	**Amount**	**%DV**	**Amount**	**%DV**
Calcium	94 mg	9.40%	55.4 mg	5.54%
Iron	3.8 mg	47.50%	0.9 mg	11.25%
Magnesium	37 mg	8.81%	35.4 mg	8.43%
Phosphorus	68 mg	9.71%	-	N/D
Potassium	419 mg	8.91%	416.3 mg	8.85%
Zinc	12.1 ppm	110.00%	0.76 ppm	6.91%
Copper	1.5 ppm	166.67%	0.85 ppm	94.45%
Manganese	41 ppm	1782.61%	-	N/D
Vitamins	**Amount**	**%DV**	**Amount**	**%DV**
Vitamin C (ascorbic acid)	1.5 mg	1.67%	61.1 mg	68.02%
Vitamin K	-	-	332.8 µg	416%
Vitamin A	-	-	627.2 µg	78.40%

N/D = not determined; DV= daily value. *Source: Lim (2013). **Source: Anisong et al. (2022).

recorded to date. The most common Gnetum species is lianas, which is found in tropical rain forests in central Africa, Asia, northern South America, and some islands between Australia and Asia such as many islands of Indonesia and Philippines. *G. gnemon* (without specific variety) is distributed from southern Thailand and Malaysia to the Solomon Islands and Fiji. (Gifford, 2018). According to research based on mitochondrial DNA, *Gnetum* is an ancient plant, dating back 2 to 5 million years (Won & Renner, 2003). Some species of *Gnetum* such as *G. gnemon* are defined as trees or shrubs. The *gnemon* varieties are mainly woody climbers, while the *tenerum* varieties are shrubs (Hou et al., 2015). *Gnetum gnemon* var. *gnemon* is a big-tall tree of 5-30 meters height and a trunk diameter of about 40 centimeters. The leaves are simple and elliptic, 15-25 cm long and 5-9 cm wide (Fell et al., 2015). It does not have a true flower, but reproduces with cones or strobili (Fell et al., 2015). The immature fruit is yellow and changes to orange and purple when it ripens during September and December (Bourke et al., 2004). *Gnetum gnemon* var. *tenerum* is a small evergreen shrub, 3 meters in height and grown under the shade of rubber trees or other perennials (personal survey) (Figure 1). Its leaves are elliptic, 7-12 cm long and 2.5-10 cm wide. In southern Thailand, this plant is a popular local vegetable highly in demand. The young leaves of G. *gnemon* var. *tenerum* are utilized as a fresh vegetable, normally cooked before consumption. The cones or strobili are produced between January and February and ripen through March and May (Astuti et al., 2016). The immature fruit is green and when fully ripe it turns to orange-red color. Both fruit peel and kernel with white-yellow flesh are sweet when ripe.

Figure 1. Liang (*Gnetum gnemon* var. *tenerum*). Source: Photographed by authors (2020) during doing contact farming.

4 Uses parts and utilization

G. gnemon var. *tenerum* is an important medium to broad-leaved vegetable in the south of Thailand. Almost every part of this plant can be used, similarly to G. *gnemon* var. *gnemon*, except the trunk because it is quite small with a 1-10 inch or 2.5-25 cm diameter. Resin from the stem is used in cosmetics such as for treatment of melasma or freckles while the roasted seeds are used as a snack food. The peeled seeds of ripe fruits are sweet to eat while their kernels are similar to nuts and be eaten raw or cooked. The young leaves are reddish orange to light green in color with a sweet creamy taste. When the leaves turn to a dark green color indicating older stage or an intermediate young state, they can be prepared in several dishes, such as cooked with eggs, in curries, coconut milk soup, or a fresh wrap for other foods, all of which are favorite dishes in Southern Thailand (Palasuwan et al., 2020). Preliminary tests found that Liang leaves were highly nutritious including essential amino acids, branched chain chlorophyll, crude fiber, and vitamins C, K, and A, the latter in the form of beta carotene (Anisong et al., 2022). Moreover, field surveys and personal contacts found that *G. gnemon var tenerum* has many interesting features such as the ability to grow in shady areas and resistance to pests and diseases. It grows well without needing insecticide which claims as almost insecticide-free, and also needs minimal fertilizing and watering. Post-harvest pruning and other managing costs are also trivial. However, there are few comprehensive studies on the prevention or elimination of diseases or weeds that affect this plant or its growth or harvesting yield. Recently, this plant has been introduced as a co-plant or intercropping with economic plant species such as rubber, palm, or fruit trees for preventing price crisis and relieve the financial constraints among farmers growing mono-crop. Therefore, *G. gnemon* var *tenerum* plant is one of the most popular vegetables in Thailand, and the government supports research on this plant, from planting through processing, for a wide variety of uses such as functional ingredients and food nutraceuticals and medical products.

5 Diabetes Mellitus (DM)

Diabetes mellitus is a critical and chronic disease of global concern. Approximately 1.5 million people died directly from DM in 2019. Diabetes occurs when the pancreas cannot produce enough insulin or when the body is resistant to insulin, which regulates blood sugar by transferring sugar into cells (World Health Organization, 2016). Among DM patients, continuous consumption of a high amount of simple carbohydrates or high energy food leads to hyperglycemia which causes potentially severe damage to the body, mainly the nerves and blood vessels. In addition, adult DM patients have two- to three-times the risk of heart attacks and strokes (The Emerging Risk Factors Collaboration, 2010). Reduction of blood flow and neuropathy (nerve damage), particularly in the feet, lead to the risk of foot ulcers, infections, and limb loss. Blindness is another serious complication of DM due to long-term accumulated damage to the retinal blood vessels (Sapra & Bhandari, 2021).

Besides health issues, the economic cost of DM in 2017 in the USA was about $327 billion with direct medical costs of $237 billion and productivity loss of $90 billion. Diabetic disease results in about 2.3 times higher expenses than other common disease. (American Diabetes Association, 2018). In addition, taking long-term antidiabetic drugs leads to concerns about side effects such as hypoglycemia, lactic acidosis, diarrhea, nausea, vomiting, and dyspepsia (Chaudhury et al., 2017). Therefore, natural plant foods or plant products with anti-hyperglycemic properties are a very interesting field for research.

6 Situation of diabetes in Thailand

The most recent report from Thailand found that the highest and lowest percents of diabetic patients per region were found in eastern and southern Thailand, respectively, with percent of 1.58 and 1.07%, respectively (Division of Non-Communicable Diseases Thailand, 2019) as shown in Table 2. The low prevalence of diabetes in the Southern region may be related to dietary and eating habits, particularly the consumption of local ingredients such as Liang leaves that are easily available and a common household food in this area. Market and field surveys and personal interviews indicated that Southern Thai people often eat fresh vegetables such as Liang (G. *gnemon* var *tenerum*), cashew nut leaves (*Anacardium occidentale* L.) and string beans (*Parkia speciose*) as popular daily side dishes. A literature review and preliminary tests found that Liang leaves contain quite high numbers of 3 major ingredients such as protein, fiber, and chlorophyll that may help lower blood sugar levels (Lim, 2013).

7 Natural anti-diabetic compounds

Following an experiment and data collection, it was found that G. *gnemon* var *tenerum* leaves contained 3 components; protein, fiber, and chlorophyll with a high potential for anti-diabetic properties (Anisong et al., 2022). A previous study found that alanine, arginine, and glutamine stimulated insulin secretion (Newsholme et al., 2006) while chlorophyllin derived from chlorophyll exhibited an anti-diabetic effect similarity to metformin (Abani et al., 2016). And fiber attenuates the absorption of sugar in the bloodstream. Following are the details concerning how *G. gnemon* works as an anti-diabetic are proposed as follows.

7.1 Effect of chlorophyllin on hyperglycemia

Chlorophyllins (CHL) are porphyrins derived from chlorophyll by replacing the magnesium atom at the center of the ring with other metals such as Cu^{2+}, Zn^{2+} and removing the phytol tail which makes the molecule water-soluble (Chaudhury et al., 2017). CHL has been shown to be a potent antioxidant by protecting mitochondria against oxidative damage induced by various reactive oxygen species (ROS) (Kamat et al., 2000). One study on the effect of CHL on hyperglycemia and hyperlipidemia in streptozotocin-induced diabetic mice found that intraperitoneal glucose tolerance tests on the IPGTT of CHL-administered group had similar blood profiles of glucose clearance to metformin. The effective dose of CHL was 50 mg/kg bw (Abani et al., 2016).

7.2 Effect of certain amino acids on insulin secretion

Both *in vivo* and *in vitro* studies have reported that some amino acids can acutely and chronically regulate insulin secretion from pancreatic β-cells (Newsholme et al., 2006). Amino acids such as glutamine, alanine, and arginine are known to increase glucose-stimulated insulin secretion (Newsholme et al., 2006). This indicates that amino acids and glucose share common pathways in the mechanism of insulin secretion as shown in Figure 2. The ATP which is mainly generated from mitochondrial metabolism is the main coupling factor in insulin secretion as discussed above, and in addition, amino acids can generate metabolic coupling factors via cytosolic or mitochondrial metabolism (Newsholme et al., 2006). In conclusion, a crucial coupling of amino acid and glucose triggers exocytosis of insulin granules.

Some enzymes, for instance, glutamate dehydrogenase, alanine aminotransferase, and aspartate aminotransferase, are involved with insulin secretion. One study found that after chronic exposure to hyperglycemia, some amino acids increased gene expression in the β-cells, which subsequently affected the insulin release (Newsholme & Krause, 2012). Therefore, some amino acids may directly or indirectly enhance insulin production. In addition, L-glutamine may influence cellular integrity (Cruzat et al., 2018). At a dose of 15-30 g/day, L-glutamine amino acid at a physiological concentration does not enhance insulin-secretory responses but a combination of amino acids or high concentrations of an individual amino acid is more effective (Krause et al., 2011).

Arginine

Arginine is known for its insulin secretion effect through electrogenic transport into the β-cells along with the mCAT2A amino acid transporter, leading to membrane depolarization, a rise in intracellular Ca^{2+} through the opening of voltage-gated Ca^{2+} channels, and then insulin is secreted. Arginine can also be converted to L-glutamate and influence insulin secretion by

Table 2. The diabetes situation in Thailand from 2016 to 2018.

Region	2016		2017		2018		Average	
	Amount	%	Amount	%	Amount	%	Amount	%
Northern	146,324	1.22	149,695	1.25	160,984	1.34	152,334	1.27
Central	212,613	1.32	214,638	1.34	227,589	1.42	218,280	1.36
Northeastern	66,280	1.10	69,715	1.16	73,412	1.22	69,802	1.16
Eastern	322,138	1.47	344,215	1.57	370,712	1.69	345,688	1.58
Southern	93,134	0.99	98,707	1.05	108,529	1.16	100,123	1.07

Source: Division of Non-Communicable Diseases Thailand (2019).

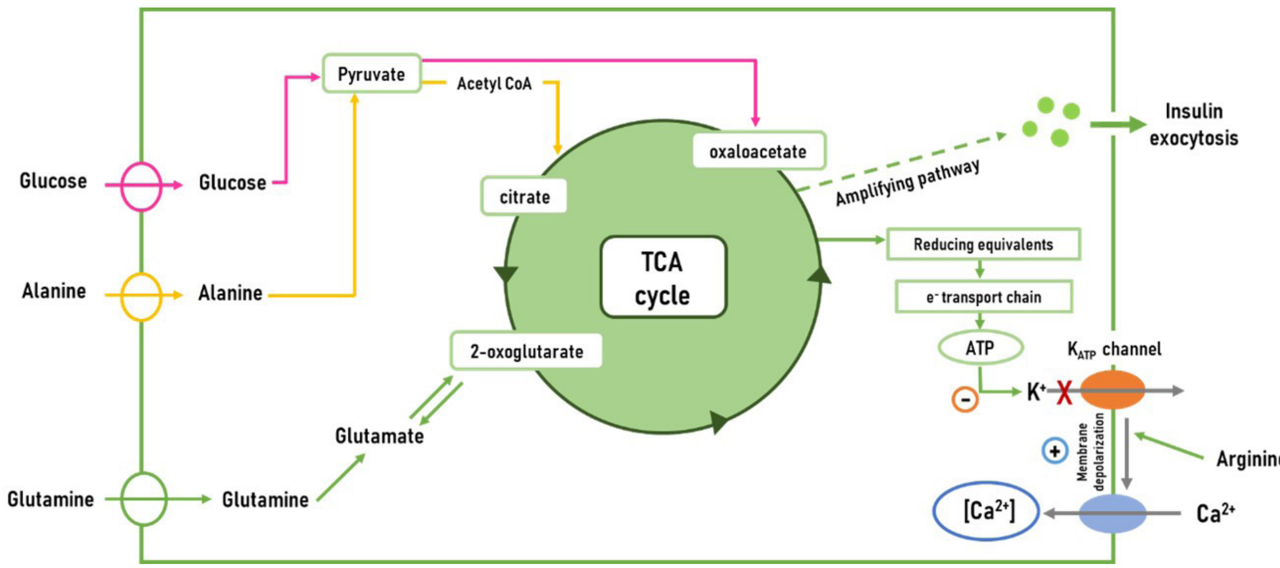

Figure 2. Possibility of regulation of insulin secretion in the β-cell stimulated by glucose and amino acids. Source: Adapted from Newsholme et al. (2006).

the production of further MCFs. It was reported that L-arginine exerts many positive impacts on β-cell metabolism, such as: i) enhancing of β-cell insulin secretion; ii) provision of antioxidant and protective responses (glutathione synthesis); iii) improving glucose consumption; and iv) initiating basal glutamate synthesis (Newsholme et al., 2006). Another study suggested a recommended effective dose of arginine in humans of 6.4-8.3 g/day (Lucotti et al., 2009).

L-alanine

The effect of prolonged exposure (24 h) to the amino acid L-alanine on the insulin secretory function, gene expression, and pro-inflammatory cytokine-induced apoptosis were investigated in clonal BRIN-BD11 cells (Cunningham et al., 2005). The study found that L-alanine provided protection to BRIN-BD11 cells from pro-inflammatory cytokine-induced apoptosis by enhancing intracellular antioxidant generation via a ROS radical process by NMA or DPI. The study found that prolonged exposure to L-alanine regulated gene expression, secretory functions, and the integrity of insulin-secreting cells. It has been hypothesized that specific amino acids may help the beta-cell function in the human body (Cheng et al., 2016). Giving 300 mg/kg L-alanine supplement to alloxan-induced diabetic rat showed a blood glucose level reduction, weight control and kidney improvement via reducing creatinine levels and liver functions enhancing via improving important parameters including aspartate transaminase (AST), alanine transaminase (ALT), and bilirubin. Also, L-alanine can regenerate Langerhans, the islets of pancreas after rat was alloxan-induced diabetic (Dandare et al., 2021). In addition, the effective dose of L-alanine in humans was found to be 2.0-4.0 g/day (Nealon et al., 2016).

L-glutamine

There have been some reports that human cells needed L-glutamine as a respiratory fuel at around 0.7 mmol/L for cell proliferation and enhancing immune cells stimulation (Newsholme, 2001). This amino acid was consumed at high rates by both primary islets and BRIN-BD11 β-cells. Although L-glutamine alone cannot stimulate insulin secretion or potentiate glucose-induced insulin secretion, it stimulates insulin secretion via the L-leucine pathway by activation of glutamate dehydrogenase (GDH) leading to an increase in L-glutamine–derived carbon into the tricarboxylic acid cycle (TCA) cycle and subsequent oxidation (Newsholme et al., 2006). Theoretically, the glutaminolysis is retarded by glucose in beta-cells (see Figure 3 for more details).

However, another study found that the addition of L-glutamine only increased intracellular glutamate concentration but with no change in insulin secretion (Newsholme et al., 2006). It is possible that the addition of L-glutamine as a precursor for L-glutamate may lead to saturating concentrations of L-glutamate without activation of the K ATP-dependent pathway. However, there was no information on the oxidation of glutamine in the process, therefore stimulus-secretion coupling via ATP was proposed as shown in Figure 3. The effective dose of glutamine in humans was stated at 15-30 g/day (Greenfield et al., 2009).

L-leucine

There are two main mechanisms of L-leucine in the stimulation of insulin release from pancreatic β- cells (Yang et al., 2010):

1) Increasing mitochondrial metabolism by activation of glutamate dehydrogenase (GDH);
2) Increasing ATP production and subsequent K ATP channel-dependent membrane depolarization. The rise of ATP levels leads to the closure of K ATP channels and depolarizes the cell membrane. This action opens voltage dependent Ca^{2+} channels then increase intracellular Ca^{2+} concentration which triggers insulin exocytosis (as shown in Figure 3).

Antioxidation has been long known to be associated with nutritional state, and it designated the potential role of certain amino acids and fatty acids supplementation for helping therapy. Therefore, amino acid supplements have been gaining popularity as a potent adjunct antidiabetic therapy. Scientific data indicated that leucine helped and protected nephropathy (DN) in women patients by activate mTORC1 which directly binding sestrin2, a negative regulator of mTORC1 activity leading to insulin secretion (Gao et al., 2021).

7.3 Effect of dietary fiber on absorption of sugar into the bloodstream

Dietary fibers (DF) are complex non-digestible carbohydrates which are not degraded in the upper gut. Normally, DFs are classified according to their water solubility, even though classification based on viscosity, gel-forming capabilities, or fermentation rate by the gut microbiota might be physiologically more relevant. Administration of soluble DF can reduce postprandial glucose excursion after carbohydrate-rich meals, as well as reducing blood total and LDL cholesterol levels. These effects can likely be explained by the viscous and/or gel-forming properties of soluble DF, by retarding gastric emptying and macronutrient absorption from the gut (Lattimer & Haub, 2010). With administration of insoluble DF, an accelerated secretion of glucose-dependent insulin tropic polypeptide (GIP) was observed in one study in healthy women (Weickert & Pfeiffer, 2008). Moreover, taking insoluble DF can result in a reduced appetite and food intake (Samra & Anderson, 2007). From the beneficial character of DF, the consumption of 25 g/day in women and 38 g/day in men has been suggested asthe required consumption level for health benefits (Weickert & Pfeiffer, 2008). The potential candidate mechanisms of DF in improving insulin sensitivity are shown in Figure 4.

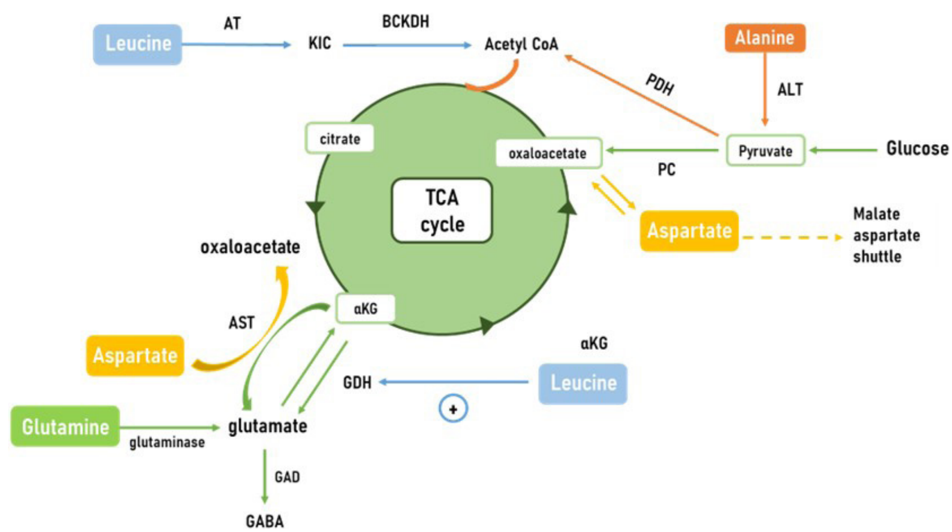

Figure 3. A schematic diagram showing the metabolism of selected amino acids and the related production of metabolic stimulus-secretion coupling factors involved in insulin release. Source: Adapted from Newsholme et al. (2006).

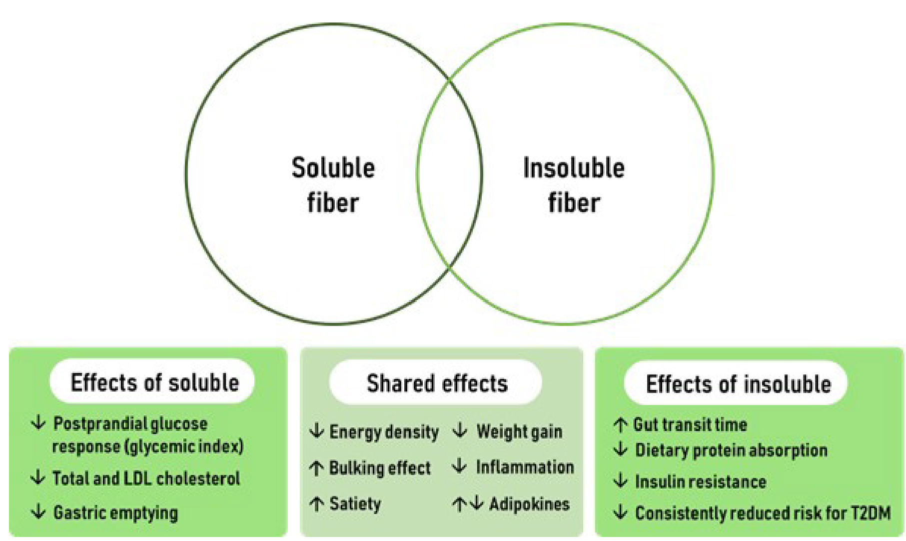

Figure 4. Effects of dietary fiber intake on various metabolic factors, insulin resistance, and the risk of developing obesity. Source: Adapted from Weickert & Pfeiffer (2008).

8 Liang (*Gnetum gnemon* var. *tenerum*) leaves-based dishes

Liang is a local medium-sized shrub vegetable in southern Thailand, which has become popular in the whole country due to its umami taste and less greenish smell compared with other leafy vegetables. Liang leaf is considered an easy-to-eat vegetable even among teenager who normally dislike vegetables because of its sweet taste, not have a disagreeable smell, and its lack of a grassy or beany flavor compared with kale, bean sprouts and so on. It has been appointed as a symbol vegetable of southern Thailand, in particular Ranong and Chumporn provinces which are promoted as lands of Liang leaves with good taste. Liang leaves are high in beta-carotene content (Lim, 2013; Anisong et al., 2022), which is beneficial to the body. Carotenoids, especially beta-carotene, are well-known antioxidants and precursors of vitamin A. Even though carrots are well known as a good source of beta-carotene, the beta-carotene in Liang leaf is similar to carrots. Liang leaves are added to a variety of dishes such as boiled in coconut soup with and without meat, stir-fried with eggs, and blanched or eaten raw as side dishes, etc., depending on household techniques and individual preferences. Some Liang dishes, ingredients, and cooking procedures are summarized in Table 3.

Table 3. Liang-based dishes commonly found on household dining tables, local food shops, and grand restaurants.

Dish name	Ingredients	Cooking procedure
Liang leaves coconut soup	- 1 bunch (100-150 g) of Liang leaves - Protein (6-7 shrimps, 1 cup of dried shrimps or 1 of crispy gourami fish) - 500 mL of coconut milk - 2 shallots and 2 garlic cloves - 1 teaspoon of shrimp paste - 1 teaspoon of salt - 1 teaspoon of sugar	Remove the leaves from the petioles and wash. Peel the shrimp, remove the heads and wash. Crush shallots and garlic cloves. Heat coconut milk, shallots and garlics and immediately add the shrimp, peeled shrimp and salt. Add the Liang-leaves and more seasoning if prefer. Serve hot with rice.
Stir-fried Liang leaves with egg	- 2 bunches (200-300 g) of Liang leaves - 2 tablespoons of palm oil or rice bran oil - 2 eggs - 1 tablespoon of garlic (chopped) - 2 tablespoons of oyster sauce - 2 teaspoons of soy sauce - 1/2 teaspoon of sugar - 1/2 teaspoon of ground white pepper	Add oil and garlic to a hot pan. Add the eggs and stir. Add Liang leaves and stir fry and immediately seasoning with oyster sauce, soy sauce, sugar, and white pepper. Stir until cooked. Serve hot with rice.
Boiled Liang leaves in coconut milk	- 1 bunch (100-180 g) of Liang leaves - 250 mL of coconut milk - 1 grilled mackerel - 1 shallot - 1 teaspoon black pepper - 1/2 teaspoon of salt - 1/4 teaspoon of sugar - 1/2 teaspoon of shrimp paste	Remove the leaves from the petioles and wash. Descale mackerel and grill. Add drinking water to a hot pot, heat until boil. Add Liang leaves, heat until soft then remove to cool down in cold water. Pound pepper, shallots and grilled mackerel then add shrimp paste, mix thoroughly. Add the chili paste in coconut milk and heat until boil and add cooked Liang leaves. Add more seasoning (salt and sugar) if prefer Serve hot with rice and any chili paste.
Liang leaves with steamed mackerel in coconut soup	- 1 bunch (100-150 g) of Liang leaves - 500 mL of coconut milk - 5 shallots - 1 steamed mackerel - 1 tablespoon tamarind sauce - 1 teaspoon of shrimp paste - 1 teaspoon of sugar	Pound shallots and steamed-mackerel before adding shrimp paste, mix thoroughly. Add the chili paste composing of black pepper, shallots, shrimp paste, and salt in coconut milk and heat until boil. Add Liang leaves, steamed-mackerel, and more seasoning if prefer. Serve hot with rice.
Southern Thai curry with blue crab	- 5-6 blue crabs - 1 bunch (100-150 g) Liang leaves - 1/2 cup of stink beans (parkia) - kaffir leaf, goat pepper - 15-20 bird chilis - 1 tablespoon of galangal - 1 tablespoon of grated lime skin - 1 teaspoon turmeric - 2 lemongrasses - 3 shallot bulbs - 1 garlic bulb - Fish sauce and sugar	Add the chili paste composing of shallots, bird chilis, galangal, lemongrasses, garlic, turmeric, and sliced kaffir lime rind in to the pot then add shrimp paste, coconut milk and heat until boil. Add Liang leaves and blue crab and immediately season with fish sauce and sugar. Add kaffir lime leaf, sliced goat pepper. Serve hot with rice.
Liang leaves omelet	- 2 bunches of Liang leaves - 2-3 eggs - 1/2 cup of sliced shallots - 3-5 sliced of bird chilis - 1 tablespoon of fish sauce	Beat the eggs and mix with washed Liang leaves, add sliced shallots and bird chilis. Add seasoning (fish sauce) and mix well. Heat plenty of oil in the pan then pour over the mixture of beaten egg and Liang leaves. Wait until the bottom is golden, then turn over. Serve hot with rice and/or chili paste.
Crispy Liang leaves	- 1 bunch of Liang leaves - 1/2 cup of crispy flour - 3-4 tablespoon of drinking water - 100 mL of palm oil or rice bran oil	Remove the leaves from the petioles and wash. Add water to flour and mix to get batter. Heat cooking oil Dip Liang leaves in batter and fry in hot oil until golden brown. Serve hot with sweet sauce or chili sauce.

Source: Marketing survey and personal interviews by authors.

9 Conclusion

From preliminary test and intensive review, Liang is a famous indigenous leafy vegetable of Thailand. It contains numerous of phytochemicals including macro and micro nutrients which are beneficial to health. However, with the diabetic problem around the world, Thailand is also faced with this issue. Diabetes is markedly affected by eating habits. Having vegetables with specific compounds regulating insulin and appetite, can play a role in diabetic management. Liang leaves, with high protein and fiber as well as chlorophyll and its water-soluble derivative chlorophyllin, have been intensively investigated for various medical aspects including anti-diabetes properties. From scientific data and laboratory results, the leaves of this plant are very likely to have a significant positive effect for diabetes patients or as future antidiabetic products.

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