Annals of Phytomedicine 4(1): 46-53, 2015

Journal homepage: www.ukaazpublications.com

ANNALS OF PHYTOMEDICINE
An International Journal

ISSN : 2393-9885

Salacia as an ayurvedic medicine with multiple targets in diabetes and obesity

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Received April 28, 2015: Revised May 20, 2015: Accepted May 25, 2015: Published online June 30, 2015

Abstract

The genus, *Salacia* belongs to the family, Celastraceae and is distributed across the world. Roots and stems of *Salacia* are used mainly as antidiabetic agents in traditional system of medicine such as Ayurveda and Unani. The roots are either chewed directly or taken in dried powdered form or as decoction. Apart from antidiabetic activity, several species of the genus *Salacia* are known to possess anti-inflammatory, antilipidemic, antiperoxidative, antimicrobial, antileukemic, astringent and antimalarial activities. *Salacia* is being used in several herbal formulations for treating diabetes and obesity. It is also used to treat skin diseases such as leprosy, ulcers, hyperhydrosis, hepatopathy and dyspepsia. The present study is focussed on reviewing the progress made on the active principles of *Salacia* species, mainly *S. oblonga* Wall., *S. reticulata* Wight., *S. chinensis* Linn. and *S. macrosperma* Wight. and previewing their potential as an effective antidiabetic medicine.

Key words: *Salacia*, antidiabetic activity, α-glucosidase inhibitors, postprandial hyperglycemia, postprandial hyperlipidaemia

1. Introduction

The genus, *Salacia* belongs to the family, Celastraceae/ Hippocrateaceae. It is a scandent or sarmentosa shrub or small tree, and has 407 different species. The leaves are usually opposite, petioled and coriaceous. Flowers are small, axillary, extra-axillary, facicled or cymose, and seldom solitary. Fruit is baccate, edible, 1-3 celled with 1-4 seeded each and pulp is mucilaginous. Seeds are large, angular, with thick testa, cotyledons are thick and usually conferruminate (Kirtikar and Basu, 1987; Nandkarni, 1993). *Salacia oblonga* Wall. is commonly known as Saptarangi, Chundan in Tamil, Ponkoranti in Malayalam, Vairi in Sanskrit and Anukuducettu in Telugu. *S. reticulata* Wight is known as Himbutu in Sinhalese, Kothala himbutu in Hindi, Saptachakra in Sanskrit and Ekanayakam in Kannada. *S. chinensis*is Linn. is commonly known as Chinese *Salacia*, Chourondi in Malayalam, Chuntan, Karukkuvai in Tamil. *S. macrosperma* Wight is commonly known as large seeded Anakoranti in Malayalam, Lendphal in Marathi (Matsuda *et al.*, 2005; Kanmani, 2012; Anshul *et al.*, 2013). Besides its main antidiabetic activity, different species of the genus, *Salacia* also exhibited hepatoprotective, antimicrobial, anti-inflammatory, antimalarial, and antiobese activities (Paarakh *et al.*, 2008). It is relatively safe to use and, hence, it is available as an ingredient in many functional foods and as a herbal drug. Because of its multifarious therapeutic properties, the plant is being over-exploited in India. If corrective measures are not taken at this stage, the plant may become extinct soon in India.

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2. Distribution of *Salacia*

These species are widely distributed in South-West India, Peninsular region of India, Sri Lanka, Vietnam, China, Indonesia, Brazil, South Africa, Malaysia, Thailand and Philippines (Saldanha, 1998; Anshul *et al.*, 2013). In India, it is well distributed in Karnataka (Western Ghats), Kerala (coastal forests of Kollam and Idukki districts) and Southern parts of Odisha (Orissa). *S.oblonga* growing in its natural habitat and images of other *Salacia* species : *S. reticulata*, *S. chinensis*is Linn, *S. macrosperma* Wight are shown in Figure 1.

3. *Salacia* and its uses in traditional system of medicine

Different species of *Salacia* have medicinal principles with a high pharmacological significance. In traditional system of medicine, different species of the genus, *Salacia* are being used as acrid, bitter, termogenic, urinary and as liver tonic. The aerial parts and roots of *Salacia* are extensively used in Ayurvedic system of medicine, traditional Indian medicine and Unani for treating diabetes, gonorrhoea, rheumatism, itching, asthma, ear diseases, leukaemia and inflammations (Kirtikar and Basu, 1987; Matsuda *et al.*, 1999; Setzer *et al.*, 2001). The multifarious uses of *Salacia* species are given in the Table 1.

4. Phytochemical constituents of *Salacia*

Phytochemical screening of *Salacia* species revealed the presence of anthocyanidines, catechins, sterols, phenolic acids, quinones, friedo-oleanones, quinonemethide, and related triterpenoids (celastroloids), alkaloids, flavonoids and tannins in the methanol and water extracts of *S. oblonga* (Basu *et al.*, 2013). Durate *et al.* (2010) identified 20 different compounds, *viz*. triterpenes (3β-stearyloxy-oleanane, 3β-stearyloxy-ursane, seco-friedelane), xanthone, polyols, caroboxylic acid, aromatic ester in *S. elliptica*.

Similarly, Wang *et al.* (2011) have reported the presence of triterpenes, including quinonemethides, friedelanes, oleananes and ursanestriterpenes, phenolics, polyol and chromanone in *S. amplifolia*. The presence of several compounds as revealed by the phytochemical analysis led to the isolation of several secondary plant products by different groups. The major bioactive constituents are xanthine, glucoside, mangiferin, and two components with unique, thiosugar structure sulfonium sulphate, *viz.* salacinol and kotalanol. Different compounds isolated from different species of *Salacia* having antidiabetic activity are shown in Table 2. Matsuda *et al*. (1999) isolated α-glucosidase inhibitors like salacinol, kotalanol from the water soluble portion and aldose reductase inhibitor, kotalgenin-16-acetate from the ethyl acetate soluble fraction of *S. oblonga* roots. Chemical structures of salacinol and kotalanol are shown in the Figure 2.

Figure 1: Different species of *Salacia*

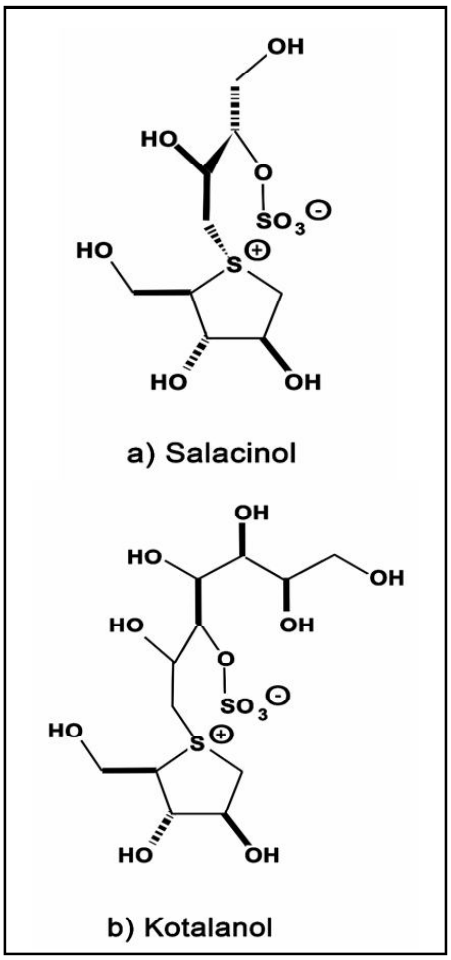

Figure 2: Structures of salacinol and kotalanol

5. Pharmacological activity of *Salacia*

5.1 Diabetes mellitus and α-glucosidase inhibitors

Diabetes mellitus, called as diabetes in common parlance, is caused by a deficiency of the pancreatic hormone insulin. Deficiency of insulin hormone results in a failure to metabolize sugars and starch. This leads to the accumulation of glucose and other sugars in the blood and urine. Further, the resulting by-products of alternative fat metabolism disturb the acid-base balance of the blood in humans, causing convulsions and coma that are fatal.Therefore, it is vital for us to look for both short-term as well long-term remedies for this dreaded disorder. α-glucosidase inhibitors are used to establish greater glycemic control over hyperglycemia in diabetes mellitus type II. α-glucosidase inhibitors may be used with an appropriate diabetic diet. They are being used in conjunction with other antidiabetic drugs. Basically, α-glucosidase inhibitors reduce the rate of digestion of complex carbohydrates. Therefore, less glucose is released for absorption. This is because the carbohydrates are not broken down into the simpler, rapidly assimilable glucose molecules. In other words, these inhibitors/therapeutic molecules have short-term effects on diabetic patients and decrease the current blood glucose levels. On the other hand, the long-term effect is a modest reduction in haemoglobin A1c level.

Table 1: Therapeutic activities of *Salacia* species

Species	Therapeutic property	Reference
S. chinensis	Anticaries, antiulcer activities	Deokate and Khadabadi (2012)
S. reticulata and several other species	Antidiabetic activity	Karunanayake *et al.* (1984) Serasinghe *et al.* (1990) Shimoda *et al.* (1998) Kajimoto *et al.* (2000) Tanimura *et al.* (2005) Jayawardena *et al.* (2005)
S. oblonga	Anti-hypertriglyceridemic activity	Wang *et al.* (2011)
S. oblonga	Anti-inflammatory activity	Ismail *et al.* (1997)
S. madagascariensis	Antimalarial activity	Gessler *et al.* (1994)
S. beddomei, S. reticulata	Antibacterial activity, Antimicrobial activity	Deepa and Narmatha (2004); Choudhary *et al.* (2005); Samy (2005); Subhasree *et al.* (2009)
S. oblonga, S. reticulata	Antiobese activity	Kishino *et al.* (2006); Akase *et al.* (2011)
S. reticulata	Antioxidant activity	Krishnakumar *et al.* (1999); Kishi *et al.* (2003) Carvalho *et al.* (2005); Subhasree *et al.* (2009)
S. reticulata	Antiproliferative activity	Sekiguchi *et al.* (2012)
S. reticulata	Antirheumatic activity	Medagama *et al.* (2015)
S. chinensis	Booster of immune system	Bhatt *et al.* (2012)
S. oblonga, S. kraussii	Cytotoxic activity	Augusti *et al.* (1995); Figueiredo *et al.* (1998); Setzer *et al.* (2001)
S. reticulata	Hepatoprotective activity	Yoshikawa *et al.* (2002)
S. chinensis	Nephroprotective activity	Singh *et al.* (2010)

5.2 α-Glucosidase inhibitors of *Salacia*

Stems and roots of *Salacia* contain potent α-glucosidase inhibitors (salacinol and kotalanol) and also the aldose reductase inhibitor, kotalgenin-16-acetate. Salacinol and kotalanol competitively bind to α-glucosidase present in the brush borders of small intestine and prevent the breakdown of oligosaccharides into monosaccharides and thus, maintain the normal blood levels in the human body (Matsuda *et al.,* 1999). The enzyme aldose reductase catalyse the conversion of glucose to sorbitol (sugar alcohol). Sorbitol do not readily diffuse across the cell membranes and gets accumulated in the lens resulting in cataract formation. Kotalgenin-16-acetate competitively binds to the aldose reductase and thus, prevents cataracts (Matsuda *et al.,* 1999). The various other active principles of *Salacia* are mangiferin, diterpenes, triterpenes, megastigmane glycosides, thiocyclitol, quinonemethides, friedelanes, oleananes, polyols and others (Matsuda *et al.,* 1999). A comprehensive review on phytochemical and pharmacological aspects of *Salacia* has been carried out by Paarakh *et al.* (2008); Singh and Duggal (2010); Deokate and Khadabadi (2012); Anshul *et al.* (2013), Deepak *et al.* (2014) and Medagama (2015). They have critically reviewed the uses of *Salacia* for treating type-II diabetes and obesity.

The two thiosugars isolated from *S. oblonga* extract, salacinol and kotalanol, have been found to have inhibitory effects, against the enzyme activities of maltase, isomaltase, and sucrose. It has also been found that the inhibitory effect against sucrase is more potent than the prescription α-glucosidase inhibitors acarbose and voglibiose that are used in the treatment of diabetes (Matsuda *et al.,* 2005). If the compounds salacinol and kotalanol bind to the enzyme α-glucosidase and prevent the breakdown of di-, tri-, and oligosaccharides, carbohydrate absorption in the intestine is decreased, attenuating the postprandial glycemic response. Therefore, the undigested di-, tri-, and oligosaccharides pass through the small intestine into the colon where they are digested by the colonic microflora producing gaseous byproducts (Wolever *et al.*,1998). Lowering of postprandial glycemia by *S. oblonga* extract has been observed in rats fed either with maltose or sucrose, but not glucose, which is consistent with its α-glucosidase inhibitory effect in the small intestine (Shimoda *et al.,* 1998).

5.3 Studies on antidiabetic activity of *Salacia* extracts

Matsuda *et al.* (1999) studied the inhibitory activity of *S. oblonga* root extract and its effect on serum glucose levels. Experiments were carried on sucrose and maltose loaded male Wistar rats (130-170 g). The rats are orally fed with 0, 100, 200 mg/kg methanolic extract of *S. oblonga*. Blood was collected from the retro-orbital sinus after 0.5 h, 1 h and 2 h and serum glucose levels were assayed. Sucrose loaded rats with 200 mg/kg methanolic extract showed reduced serum glucose levels. Maltose loaded rats fed with methanolic extract did not show significant decrease in serum glucose levels. *S. oblonga* extract showed postprandial glycemic activity in a randomized possible study of 43 healthy experimental subjects. The control subjects were fed with 480 ml of study beverage containing 82 g of carbohydrate, 20 g of protein and 14 g of fat and separately another subject control was fed with 1000 mg of *S. oblonga* extract. Plasma glucose levels were measured for 180 min which showed that the base line adjusted peak glucose response was not different across the meals (Collene *et al.,* 2005). Williams *et al.* (2007) also studied the effect of herbal extracts of *S. oblonga* on 66 patients with type II diabetes.

Table 2: Different constituents isolated from *Salacia* species showing antidiabetic activity

Name of the plant	Geographic location	Plant part used	Constituents isolated	References
S. oblonga	India and Sri Lanka	Root	Salacinol; kotanolol; kotalagenin 16 acetate, (glycerol; D-fructose; D-glucose; sucrose; galactinol; 3-O-a-D-galactopyranosyl (1 → 6)-O-b-D-galactopyranosyl-sn-glycerol; raffinose; stachyose, 26-hydroxy-1, 3-friedelanedione; 19-hydroxyferruginol; lambertic acid; 49-O-methylepigallocatechin; maytenfolic acid; 3b,22a-dihydroxyolean-12-en-29-oic acid; few diterpenes and triterpenes	Matsuda *et al.* (1999)
S. reticulata	Tamil Nadu,	Root	Salacinol	Yoshikawa *et al.* (1997)
	India		Kotalagenin 16 acetate, 26-hydroxy 1, 3 fridelanedione; maytenfolic acid, 3 β, 22-dihydroxy olean-12en-29 oic acid;	Gunatilaka *et al.* (1993)
			kotanolol	Yoshikawa *et al.* (1998)
			(-)-Epicatechin; (-)-epigallocatechin, (-)-4'-O-methylepigallocatechin, (-)-epiafzelechin -(4ß 8)-(-)-4'-O- methylepigallocatechin,	Karunanayake *et al.* (1985)
			(-)-epicathechin-(4ß 8)-(-)-4'-O-methyle-pigallocatechin	Tezuka *et al.* (1994)
			Mangiferin	Dhanabalasingham *et al.* (1996)
			Salaciquinone; Isoiguesterinol; 30 hydroxy pristimerin; netzahualcoyene	
		Stem	Iguesterin; pristimerin; epikokoondiol; thiocyclitol	Kumar *et al.* (1985) Oe and Ozaki (2008)
S. macrosperma	Western Ghats, India	Root	24-hydroxy-3-oxofriedelan-29-oic acid hemiacetal	Viswanathan (1979)
			Saptarangi quinine A, B,C salaciaquinonemethide; pristimerin tingenone; hydroxytingenone salaspermic acid	Rogger *et al.* (1980)
S. chinensis	India	Stem and leaves	Leucopelargonidin, dulcitol;Thirteen megastigmane glycosides, foliasalaciosides (A1, A2, B1, B2, C, D, E1, E2, E3, F, G, H, I); seven new phenolic glycosides, foliachinenosides (A1, A2, A3, B1, B2, C, D), four dammarane-type, three lupane-type, and an oleanane-type triterpenes named foliasalacins A1, A2, A3, A4, B1, B2, B3, C from leaves and triterpenes	Rastogi and Mehrotra (1960) Nakamura *et al.* (2008) Zhang *et al.* (2008) Yoshikawa *et al.* (2008) Krishnan and Rangaswami (1967) Kishi *et al.* (2003) Morikawa *et al.* (2003)
			Salasone D and E; salaquinone B; salasol B; Salas one A,B,C; salaquinone A; salasol A; 3β, 22β dihyroxy olean-12-en-29-oic acid; tingenone; tingenin B; regeol A; triptocalline A; mangiferine; Salacinol; Fridel-1-en-3-one; friedelan-1,3,dione 7 α-ol; friedelan-1,3,dione-24 al; friedelan-1,3 dione; friedelan-1,3 dione,24 ol;friedelan-1,3 dione-24-oic acid; 24,25-oxidofriedelan-1,3 dione; 7,24-oxidofriedelan -1,3 dione; 25,26 -oxidofriedelan-1,3 dione; Proanthocyanidin	Yoshikawa *et al.* (2003) Rastogi and Mehrotra (1970)
S. amplifolia	China	Aerial parts	Triterpenes, including quinonemethides, friedelanes, oleananes, ursanes triterpenes, simple phenolics, polyol, chromanone 2-hydroxyfriedelan-3-one, friedelin, lup-20 (29)-en-3, 21-dione, D-friedoolean-14-en-3 -one, 3-(32 2 , 42 2 -dihydroxy-transcinnam-oyloxy)-D-friedoolean-14-en-28-oic acid, 3, 22-dioxo-29-normoretane, Lupeol, β-Sitosterol, β-Daucosterol	Wang *et al.* (2011)
S. campestris	Brazil	Root	Salacin, pristimerin, maytenin, 20 α-hydroxymaytenin, and netzahualcoyene; Maytenin	Carvalho *et al.*(2005) Corsino *et al.* (2000)
S. elliptica	Brazil	Root	3β-stearyloxy-oleanane, 3β-stearyloxy-ursane, one seco-friedelane), xanthone, polyols, caoboxylic acid, aromatic ester	Durate *et al.*(2010)

Postprandial glycemia and blood insulin levels were estimated in the subjects. The patients were categorized into 3 groups and each group was served with a control meal, control meal with 240 mg of *S. oblonga* extract and control meal with 480 mg/ml of *S. oblonga* extract. Both the concentrations significantly lowered the postprandial positive area under the glucose curve. Significant decreases of 14% and 22% in 240 mg and 480 mg extract-fed patients were recorded, respectively. A mixture of *S. oblonga* extract IP-PAI (SI tea) decreased the plasma glucose levels as reported by Nakata *et al.* (2011). SI tea significantly decreased the plasma glucose levels in KK-Ay/TaJcl type-II diabetic model mice.

Bhagyajyothi *et al.* (2012) studied various parameters such as random blood glucose levels, serum insulin, glycated haemoglobin and serum lipid profile with hydroalcoholic root extract of *S. oblonga*. Streptozotocin induced diabetic Wistar rats fed with 50 mg/kg and 100 mg/kg body weight *S. oblonga* extract showed 44% and 45% decrease in random blood glucose levels. The study showed significant increase in serum insulin and HDL-cholesterol and a significant decrease in plasma HbA1C and serum triacyl glycerol. Karunanayake *et al.* (1984) have evaluated the aqueous decoction of 40 Sri Lankan medicinal plants that are known to lower blood glucose levels. A maximum reduction of 30% blood glucose was seen in the Sprague-Dawley rats fed with decoction of *S. reticulata.* Serasinghe *et al.* (1990) have evaluated the aqueous extract of *S. reticulata* on streptozotocin induced diabetes rats to study its effect on plasma glucose levels. The experimental rats were orally fed with 0.5, 1 and 5 g/kg body weight and the plasma glucose levels were reduced by 42.8%, 45.4% and 87.5%, respectively. Aqueous extract of *S. reticulata* stems showed decrease in serum glucose levels when the rats were fed with sucrose, maltose and starch. Shimoda *et al.* (2000) also showed the strong inhibitory activities of α-glucosidase prepared from yeast and rat jejunum. Aqueous extracts from the roots of *S. reticulata* (200 mg) significantly suppressed the postprandial hyperglycemia when healthy human volunteers were loaded with 50 g of sucrose. Yoshikawa *et al.* (1998) used bioassay guided separation to isolate kotalanol from *S. reticulata* root. Significant reduction in serum glucose level was noticed in hydrocortisone induced hypoglycemic rat models when fed with 500 mg/kg body weight of hydroalcoholic extract of *S. reticulata* (Rabbani *et al.*, 2006).

Oe and Ozaki (2008) isolated a thiocyclitol, novel 13-membered ring from the aqueous stem extracts of *S. reticulata*. The activity was tested on maltose and sucrose loaded Wistar rats and the extract significantly lowered the postprandial glucose levels. Thiocyclitol was also checked for α-glucosidase inhibitor activity in *in vivo* conditions. Shivaprasad *et al.* (2013) have evaluated the efficacy and safety of leaves and root bark of *S. reticulata* in a randomized, double-blind, placebo controlled method. The study was carried on patients with prediabetes and mild to moderate hyperlipidemia for 6-weeks. Twenty nine patients were fed with placebo or 500 mg twice a day with *S. reticulata*. Nine individuals were fed with placebo, 11 with *S. reticulata* leaves and 9 with *S. reticulata* roots. The results revealed a statistically significant decrease in fasting blood sugar levels and low-density lipoprotein cholesterol with no side effects. Jayawardena *et al.* (2005) investigated the effect of herbal tea extracts of *S. reticulata* in patients with type II diabetes in a randomised single centre, double blind method. The extract showed significant decrease in HbA1C and Jayawardena *et al.* (2005) concluded that *S. reticulata* herbal tea is safe and effective. Kajimoto *et al.* (2000) recorded a significant reduction in fasting plasma glucose levels, HbA1C and BMI in placebo group fed with aqueous stem extracts of *S. reticulata*.Venkateswarlu *et al.* (1990) have evaluated the antidiabetic activity of chloroform, ethanol and aqueous root extracts of *S. macrosperma* on alloxan-diabetic rats and rabbits. The experimental rabbits were administered with 200 mg/kg body weight of crude and chloroform extracts. The alloxan-diabetic rats were administered with 150 mg/kg body weight of ethanolic extract. Ethanolic extract lowered the blood glucose levels in rabbits and rats. Venkateswarlu *et al.* (1993) have checked for antidiabetic activity in alloxan-diabetes rats. Alcoholic and methanolic root extracts of *S. macrosperma* were tested and methanolic fraction has shown a better antidiabetic activity.

Sellamuthu *et al.* (2009) evaluated antihyperglycemic activity of mangiferin purified from methanolic root extracts of *S. chinensis* on streptozotocin induced diabetic rats. Forty mg/kg body weight was orally administered to the streptozotocin induced diabetic rats. Mangiferin treated diabetic rats exhibited significantly reduced blood glucose levels, glycosylated haemoglobin, and increased levels of insulin and haemoglobin. Joshi *et al.* (1973) isolated salacinol and Morikawa *et al.* (2003) isolated aldose reductase inhibitor from *S. chinensis*. Yoshikawa *et al.* (2003) studied the antidiabetogenic activity of methanolic extract of *S. chinensis*. Rats fed with the methanolic extract showed antihyperglycemic effect in oral sucrose or maltose loaded rats. Morikawa *et al.* (2003) showed that different constituents of *S. chinensis* showed the inhibitory effect on aldose reductase of rat and thus, signifying its antidiabetic potential.

6. Hepatoprotective activities of *Salacia*

Yoshikawa and co-workers (Yoshikawa *et al.*, 2002) have tested the hepatoprotective activities of *S. reticulata*, using an oxidative stress-induced liver injury model. The extracts of the plant (400 mg/kg weight) considerably suppressed the glutamic oxaloacetic transaminase (GOT), and glutamic pyruvic transaminase (GPT) activities in carbon tetrachloride (CCl_4) treated mice. The extracts of *S. reticulata* also inhibited CCl_4 induced thiobarbituric acid reactive substance (TBARS) formation. These results indicated that the CCl_4 induced increase in lipid peroxidation in the liver is being protected by *Salacia* extracts (Yoshikawa *et al.*, 2002).

7. Antioxidant activities of *Salacia*

Yoshikawa *et al.* (2002, 2003) studied the antioxidant activities of hot aqueous and methanolic extracts of *S. reticulata* and *S. chinensis*. They used mangiferin, (-)-4'-O-methylepigallocatechin and (-)-epicatechin-(4β-8)-(-)-42 -O-methylepigallocatechin for antioxidative activity. They observed scavenging activity of DPPH radicals by the above compounds. Triterpenes like salacin, pristemerin, maytenin, 20 a-hydroxymaytenin and netzahualcoyene derived from *S. campestris* have recorded inhibition of DPPH radical activity (Carvalho *et al.*, 2005). Likewise, salaquinone B and catechin isolated from *S. chinensis* have been reported to have radical scavenging activity against DPPH (Kishi *et al.*, 2003). Vellosa *et al.* (2009) observed that ethanolic root extract of *S. campestris* possess free radical scavenging and antioxidant activity. High phenolic content and good antioxidant activity was reported in *S. chinensis* reported by Chavan *et al.* (2013). Krishnakumar and co-workers (Krishnakumar *et al.*, 1999, 2000) have found antilipid peroxidative activity in the cardiac tissues of streptozotocin diabetic rats. The rats also showed increased GSHPxase and GSSGRase enzymes in the cardiac tissues. Thus, it appears that several secondary plant products of *Salacia* species have significant antioxidant activities.

8. Antiobese activities of *Salacia*

Salacia has been known to control obese problems. Its activity on obese patients has been extensively studied. Pancreatic lipase, a well-known enzyme is highly critical for the digestion of dietary fat. Therefore, it is believed to contribute towards weight reduction in humans (Li *et al.*, 2008). Huang *et al.* (2006) reported lipid-lowering activity from the root extracts of *S. oblonga* and also demonstrated olive oil induced inhibition of hypertriglycerdiaemia of rats by using the root extracts *S. oblonga*. Suppression of pancreatic lipase activity has also been reported by *S. reticulata* (Yoshikawa *et al.*, 2002). Hence, it appears that the inhibition of pancreatic lipase activity in the small intestine is vital and perhaps is one of the important mechanisms for the attenuation of postprandial hyperlipidaemia as noted by Li *et al.* (2008). Thus, different species of *Salacia* appear to have multiple targets in controlling diabetes and obesity.

9. Antiproliferative activities of *Salacia*

Sekiguchi *et al*. (2012) studied the antiproliferative activities of *S. reticulata* leaves in interleukin-1-β-activated cells. The extract (850 μg/ml) showed 50% inhibition in synoviocyte like cell lines (inflammatory synovial tissues) and also suppressed matrix metalloproteinase genes. Minh *et al*. (2010) reported anticancer activity in 4 cancer cell lines with triterpenoids isolated from *S. chinensis.* The results indicate that *Salacia* has significant anti-proliferative activity.

10. Anti-inflammatory activity of *Salacia*

Anti-inflammatory activity of *S. oblonga* was studied by Ismail *et al*. (1997), using carrageenan-induced paw oedema and cotton pellet granuloma methods. *S. oblonga* showed an increased acid and alkaline phosphatase activity and decreased serum albumin in cotton pellet granulomatous rats.

11. Antimicrobial activity of *Salacia*

Antimicrobial activity of *S. oblonga*, *S. chinensis*, *S. macrosperma* and *S. beddomei* was studied against bacteria and fungi (Deepa and Narmathabai, 2004; Samy, 2005; Anjaneyulu *et al*., 2013). The studies showed *Salacia* has good antimicrobial activity against several pathogenic bacteria and fungi.

12. Toxicological and genotoxic studies on *Salacia*

Flammang *et al.* (2006, 2007) evaluated the toxicological effects of root extracts of *S. oblonga* in rats for 90 days. They noticed no chromosomal aberration in rat blood lymphocytes cultured *in vitro*. Genotoxicity was also studied by the same group using human lymphocytes. Root extracts of *S. oblonga* were used in these experiments and chromosomal aberration assay, and micronucleus assay were performed. The results revealed no genotoxic effect by root extracts of *Salacia* species. However, in many investigations, it has been found that *S. oblonga* extracts lowered the postprandial glucose response by 25-30% and the postprandial lactate response by 29-35%. It has been noticed that the extract did not cause any significant differences in perceived nausea, headache, abdominal cramping, bloating/excessive fullness, or satiety. The extracts of *S. oblonga* caused an increase in perceived flatulence, indicating the α-glucosidase activity of the extract. Further, it has been reported that taking *Salacia* tea can cause dyspepsia and loose stool (Tanimura *et al.*, 2005).

13. Conclusions

The important active principles of *Salacia* species such as salacinol and kotalanol, the potent α-glucosidase inhibitors showed effective reduction of plasma glucose in animal and human studies. All the studies discussed above provide an insight of the antidiabetic action similar to standard glucosidase inhibitors. The above studies showed α-glucosidase inhibition is an important mechanism in reducing postprandial glucose levels, reduced fasting glucose and improves glucose handling. Since toxicity levels are negligible, the compounds have the potential to be used as effective α-glucosidase inhibitors and for controlling glucose levels. Further, the extracts also proved to have excellent antioxidant capacity besides antiobese activity. It is a highly promising herbal drug that can be used for effectively treating ailments like diabetes and obesity, the two dreaded disorders.

Acknowledgements

KGKD and CS are thankful to the GITAM University, Visakhapatnam, India for providing the facility and support. CS is thankful to Department of Science and Technology (DST), New Delhi for funding the project SR/FT/LS-32/2010, and University Grants Commission (UGC), New Delhi for project 42-180/2013(SR). KGKD is thankful to DST, New Delhi for supporting with JRF and SRF in the project SR/FT/LS-32/2010. PBK is thankful to the CSIR, New Delhi, for providing CSIR-Emeritus Fellowship.

Conflict of interest

We declare that we have no conflict of interest.

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