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Critical Review

The noni fruit (*Morinda citrifolia* L.): A review of agricultural research, nutritional and therapeutic properties

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Abstract

Morinda citrifolia L., the "noni", has been used in traditional Polynesian medicine for over 2000 years. *Morinda citrifolia* (Rubiaceae) is an evergreen shrub whose ripe fruit has a strong butyric acid smell and flavor. The leaves and especially the fruit are consumed in different forms by various communities (e.g., the Polynesians) throughout the world; the root is used as a dye. As a result of these uses and the market that is developing around "noni juice", it has become increasingly important to confirm the actual therapeutic properties of this plant. While recent studies have shown that this fruit has antibiotic and antioxidant properties in vitro, we still do not have scientific evidence supporting the nutritional and medicinal values of noni in humans. However, both the fruit and damnacanthal, an anthraquinone compound extracted from noni roots, are currently being studied in the context of anti-cancer research. If, in the future, the nutritional and medical values of the noni can be assessed, especially its anti-cancer activity, this fruit could play a noticeable economic role in producing countries.
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Keywords: *Morinda citrifolia* L.; Noni; Therapeutic properties; Damnacanthal

1. Introduction

Noni is the Hawaiian name for the fruit of *Morinda citrifolia* L. (Rubiaceae). Its various vernacular names are: "Indian mulberry", "nuna", or "ach" on the Indian subcontinent, "mengkudu" in Malaysia, "nhau" in Southeast Asia, "painkiller bush" in the Caribbean, or "cheese fruit" in Australia (Morton, 1992; Nelson, 2001; Ross, 2001; Wang et al., 2002; Cardon, 2003). Noni is native from Southeast Asia to Australia and is cultivated in Polynesia, India, the Caribbean, Central and northern South America (Dixon et al., 1999; Ross, 2001).

The Polynesians have been using the noni plant for food and medicinal purposes for more than 2000 years (Earle, 2001). In traditional pharmacopoeia, the fruit is claimed to prevent and cure several diseases. It is primarily used to stimulate the immune system and thus to fight bacterial, viral, parasitic and fungal infections; it is also used to prevent the formation and proliferation of tumors, including malignant ones (Dixon et al., 1999; Earle, 2001). Noni juice is also claimed to relieve inflammation. Most noni is consumed as juice, although leaves, flowers, bark and roots can also be used (Dixon et al., 1999; Earle, 2001; McClatchey, 2002).

Noni has recently been the object of many claims concerning its nutraceutic properties. Various publications have shown that noni can be used to relieve different diseases, and its registered uses span the Pacific and Asia, as well as Africa. Two clinical studies reported a relief of arthritis and diabetes associated with noni consumption (Elkins, 1998; Solomon, 1999): the observed beneficial effects may result from certain compounds such

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as scopoletin, nitric oxide, alkaloids and sterols, and also to the antioxidant potential of noni. As a result of this reputation, consumption of this fruit is currently high, not only in the producing countries, but also in the United States, Japan and Europe.

In response to this demand, some countries such as Costa Rica and Cambodia, have increased the fields being cultivated in noni. In these countries, the fruit is often commercialized fresh or as juice in both formal and informal markets, but it is also found as pasteurized juice, either pure or mixed with other juices (usually grape or blackberry). Commercial interest in noni has tremendously increased in recent years, as provided by the number of patents registered. In the United States alone, 19 patents have been registered by the US Patent and Trademark Office since 1976 (USPTO, 2005). Noni juice has been recently accepted in the European Union as a novel food (European Commission, Scientific Committee for Food, 2002). Nevertheless, despite the real market opportunities, there has been little scientific research to review the actual nutritional and functional properties of noni products. Furthermore, the phytochemical compounds responsible for their alleged properties have not yet been reviewed. As a result, optimization of agricultural/post-harvest practices or processing technologies has been neglected. This paper attempts to report on the state of progress on noni fruit production and its characterization, and the main nutritional and functional properties attributed to noni that have been scientifically proven.

2. Plant description

The genus *Morinda* (Rubiaceae), including the species *Morinda citrifolia* L., is made up of around 80 species. *Morinda citrifolia* is a bush or small tree, 3–10 m tall, with abundant wide elliptical leaves (5–17 cm length, 10–40 cm width). The small tubular white flowers are grouped together and inserted on the peduncle. The petioles leave ring-like marks on the stalks and the corolla is greenish-white (Morton, 1992; Elkins, 1998; Dixon et al., 1999; Ross, 2001; Cardon, 2003).

The noni fruit (3–10 cm length, 3–6 cm width) is oval and fleshy with an embossed appearance (Photo 1). It is slightly wrinkly, semi-translucent, and ranges in colour from green to yellow, to almost white at the time of picking. It is covered with small reddish-brown buds containing the seeds. The ripe fruit exhales a strong butyric acid-like rancid smell (Morton, 1992; Dixon et al., 1999). The pulp is juicy and bitter, light dull yellow or whitish, gelatinous when the fruit is ripe; numerous hard triangular reddish-brown pits are found, each containing four seeds (~3.5 mm) (Dittmar, 1993).

Photo 1. Unripe fruit (black and white).

3. Yields

Morinda citrifolia is a perennial bush and it is possible to find fruits at different stages of maturity on the same plant at the same time. The species is generally found from sea level to 400 m altitude, although it adapts better to coastal regions (Lüberck and Hannes, 2001). Under favorable conditions, the plant bears fruit about nine months to one year after planting. At this stage, the fruits can be harvested, but they are generally small and the yield per tree is low. Some producers choose not to harvest in the first year, and they prune in order to let the bush grow stronger. In Hawaii, noni fruits are harvested throughout the year, although there are seasonal patterns in flowering and fruit bearing (meteorological factors, fumigation, and irrigation) (Nelson, 2001, 2003).

In Hawaii, noni plots are usually harvested two or three times per month, although fruit production is lower during winter. With a density of 638 plants per hectare with good soil fertility, drainage, and irrigation and appropriate pest, disease and weed control, along with an appropriate fertilization plan, it is possible to obtain yields of between 7 tonnes/ha/year in the second year after planting to approximately 70 tonnes/ha/year after the fifth year (Nelson, 2001, 2003). With a juice extraction rate of approximately 50% (w/w), one hectare can thus yield around 35 tons of juice. However, many factors may affect these yields, and most producers do not obtain such good results because of diseases or poor agricultural practices (grown wild plants). In Hawaii, an average annual yield of 50 tonnes/ha is generally attained (Nelson, 2001, 2003).

Depending on the post-harvest technology programme adopted, the fruits may be harvested at different stages of development and continue to mature. The evolution of the colour and firmness of fruits left to ripen naturally on the tree is reported in Table 1. Nonetheless, most processors buy noni harvested at the "hard white" stage for juice production, as the fruits become soft too quickly once this

Table 1
Evolution of fruit skin colour and firmness in the course of ripening

Maturity stage	Colour	Firmness
1	Dark green	Very hard
2	Green-yellow	Very hard
3	Pale yellow	Very hard
4	Pale yellow	Fairly hard
5	Translucent- grayish	Soft

stage is reached (Nelson, 2001, 2003). The change from stage 4 to stage 5 occurs very quickly (few hours) and the pulp practically liquefies and turns from green to white, as well as developing the characteristic butyric smell.

The fruits are individually selected on the tree and harvested by hand. At the "hard white" stage, they are well able to withstand being transported in baskets or containers, and exposure of the fruits to light or high temperatures immediately after harvest does not affect their overall quality. Before processing, fruits are ripened at room temperature for a day or more, depending on the end product (tea, juice, pulp, dietetic products, etc.) (Nelson, 2003).

4. Chemical composition of noni

About 160 phytochemical compounds have been already identified in the noni plant, and the major micronutrients are phenolic compounds, organic acids and alkaloids (Wang and Su, 2001). Of the phenolic compounds, the most important reported are anthraquinones (damnacanthal, morindone, morindin, etc.), and also aucubin, asperuloside, and scopoletin (Fig. 1) (Wang and Su, 2001). The main organic acids are caproic and caprylic acids (Dittmar, 1993), while the principal reported alkaloid is xeronine (Heinicke, 1985).

However, chemical composition differs largely according to the part of the plant, as shown in Table 2. The complete physico-chemical composition of the fruit has not yet been reported and only partial information is available on noni juice (Table 3). The fruit contains 90% of water and the main components of the dry matter appear to be soluble solids, dietary fibers and proteins (Chunhieng, 2003). The fruit protein content is surprisingly high, representing 11.3% of the juice dry matter, and the main amino acids are aspartic acid, glutamic acid and isoleucine (Chunhieng, 2003).

Minerals account for 8.4% of the dry matter, and are mainly potassium, sulfur, calcium and phosphorus; traces of selenium have been reported in the juice (Chunhieng, 2003).

Vitamins have been reported in the fruit, mainly ascorbic acid (24–158 mg/100 g dry matter) (Morton, 1992; Shovic and Whistler, 2001), and provitamin A (Dixon et al., 1999).

Phenolic compounds have been found to be the major group of functional micronutrients in noni juice: damnacanthal, scopoletin, morindone, alizarin, aucubin, nordamnacanthal, rubiadin, rubiadin-1-methyl ether and other anthraquinone glycosides have been identified in noni (Fig. 1) (Morton, 1992; Dittmar, 1993; Dixon et al., 1999; Wang and Su, 2001). Damnacanthal is an anthraquinone that has been characterized recently and has some important functional properties (mainly anti-carcinogenic) (Solomon, 1999). Scopoletin is a coumarin that was isolated in 1993 at the University of Hawaii and has been found to have analgesic properties as well as a significant ability to control serotonin levels in the body (Levand and Larson, 1979). Other researchers have shown that scopoletin may also have anti-microbial (Duncan et al., 1998) and anti-hypertensive effects (Solomon, 1999).

Different Hawaiian teams (Heinicke, 1985; Solomon, 1999) reported the presence of a novel component, proxeronine, in the noni: it would be the precursor of xeronine, an alkaloid that is claimed to combine with human proteins, improving their functionality. These authors attribute most of all the beneficial effects of noni to xeronine. Nonetheless, neither the chemical characterization of this alkaloid has been published nor the method used to assess its content.

About 51 volatile compounds have been identified in the ripe fruit (Sang et al., 2001), including organic acids (mainly octanoic and hexanoic acids), alcohols (3-methyl-3-buten-1-ol), esters (methyl octanoate, methyl decanoate), ketones (2-heptanone), and lactones [(E)-6-dodeceno-γ-lactone] (Farine et al., 1996).

5. Biological activity of *Morinda citrifolia*

5.1. Anti-microbial effects

The anti-microbial effect of noni may have been the first observed property: indeed, the fruit contains relatively large amounts of sugars that are not fermented when fruits are stored in closed containers at ambient temperature. This property is used to transport the fruit by boat from the scattered Pacific islands to processing plants without specific treatment.

It has been reported that noni inhibits the growth of certain bacteria, such as Staphylococcus aureus, Pseudomonas aeruginosa, Proteus morgaii, Bacillus subtilis, *Escherichia coli*, Helicobacter pylori, Salmonella and Shigella (Atkinson, 1956). The same author claims that the anti-microbial effect observed may be due to the presence of phenolic compounds such as acubin, L-asperuloside, alizarin, scopoletin and other anthraquinones. Another study showed that an acetonitrile extract of the dried fruit inhibited the growth of Pseudomonas aeruginosa, Bacillus subtilis, *Escherichia coli*, and Streptococcus pyrogene (Locher et al., 1995).

It has also been found that ethanol and hexane extracts of noni have an antitubercular effect since they inhibit by 89–95% the growth of Mycobacterium tuberculosis (Saludes et al., 2002). The major components identified in the hexane extract were E-phytol, cycloartenol, stigmasterol, β-sitosterol, campesta-5,7,22-trien-3-β-ol, and the ketosteroids, stigmasta-4-en-3-one and stigmasta-4-22-dien-3-one.

Other studies have reported a significant antimicrobial effect on different strains of Salmonella, Shigella, and *E. coli* (Bushnell et al., 1950; Dittmar, 1993). Furthermore, they showed that the anti-microbial effect is highly dependent on the stage of ripeness and on processing, being greater when the fruit is ripe, without drying.

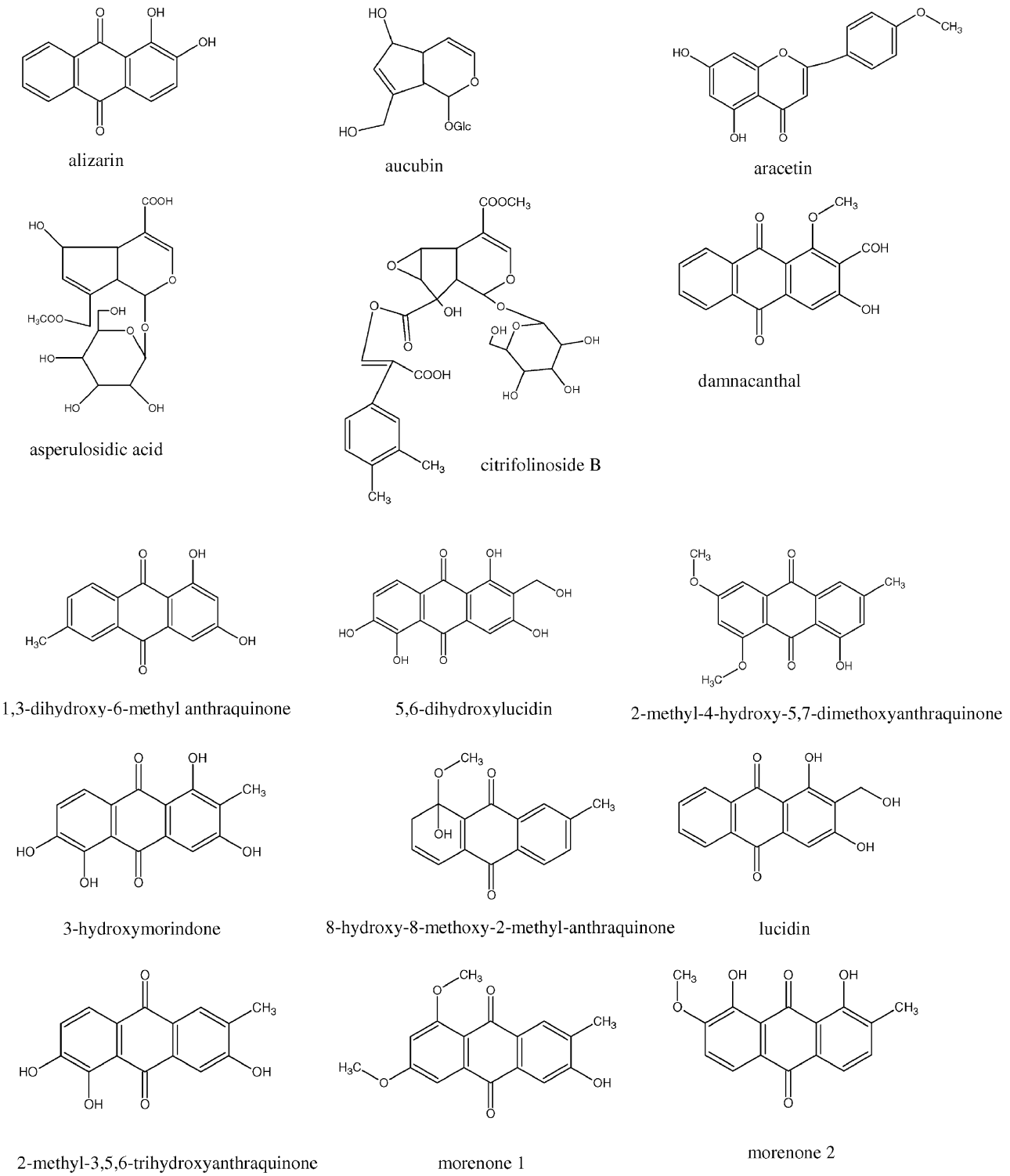

Fig. 1. Chemical structures of molecules.

5.2. Anti-cancer activity

The immunomodulatory properties (capacity to enhance the host immune system) of noni juice have recently been studied by a Japanese research team (Hirazumi et al., 1996; Hirazumi and Furusawa, 1999). The ethanol precipitable fraction (ppt) of noni juice, corresponding to a polysaccharide-rich substance composed of glucuronic acid, galactose, arabinose, and rhamnose, has been found to have immunomodulatory and anti-tumor effects against Lewis lung carcinoma (LLC). On cell models, noni-ppt seems to stimulate the production of T-cells, thymocytes and macrophages that produce cytokines, which are important mediators of tumor cytostasis and cytotoxicity.

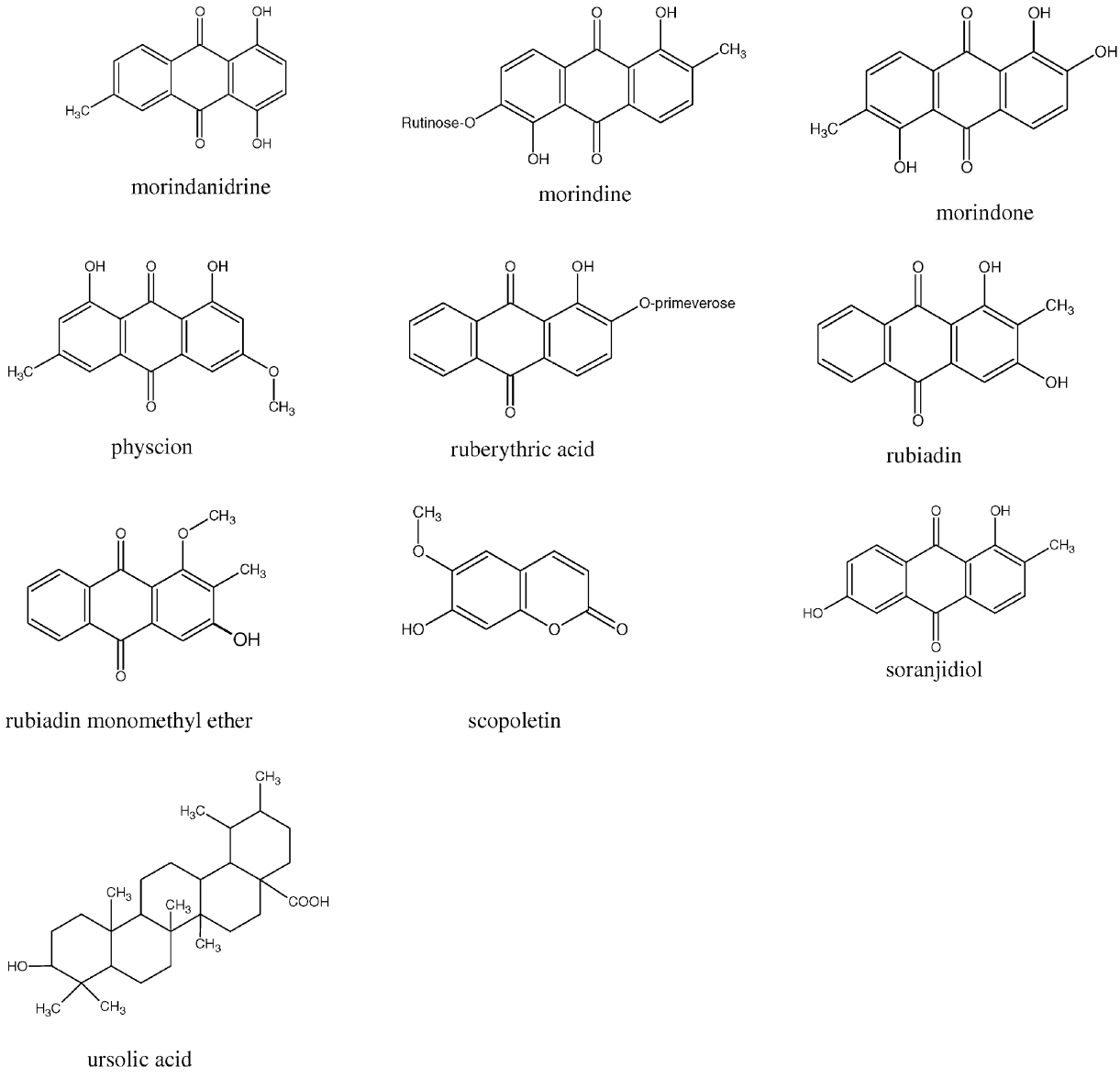

Fig. 1. (*Continued*)

Noni-ppt also appears to stimulate the release of several mediators from murine effector cells such as cytokines, which slow down the cell cycle in tumors, increase the response of cells to other immunized cells that fight tumor growth, and have a potent macrophage activator activity, suspected of playing a role in the death of tumors (Hirazumi et al., 1996; Hirazumi and Furusawa, 1999).

The same research inoculated mice with LLC, those ingesting a daily dose of 15 mg of noni juice had a significant increase (119%) in life span. Nine out of 22 mice with terminal cancer survived for more than 50 days. In addition, the ingestion of noni-ppt, combined with conventional chemotherapy in the treatment of mice with cancer, proved to increase life spans (Hirazumi et al., 1994).

Another Japanese team studied more specifically the influence of damnacanthal, an anthraquinone extracted from a chloroform extract of noni roots. Surprisingly, the researchers found that damnacanthal induced the normal morphology of a particular type of cells found in human neoplasias (K-ras-NKR cells) that multiply uncontrollably and are highly malignant (Hiramatsu et al., 1993).

Another study showed that commercial noni juice (Tahitian Noni® Juice) prevents the formation of chemical carcinogen-DNA-adduct. In this study, rats with artificially induced cancer in specific organs were fed for one week with 10% noni juice in their drinking water and rat food (rat chow), ad libitum. They showed reduced DNA-adduct formation, depending on sex and considered organ. Reduction rates were: in female rats, heart 30%, liver 42%, lungs 41%, and kidneys 80%; in male rats, heart 60%, liver 70%, lungs 50%, and kidneys 90% (Wang and Su, 2001).

Table 2
Location of chemical compounds in the plant

Location	Chemical constituents	Reference	Location	Chemical constituents	Reference
Flower	[a]**2-methyl-4-hydroxy-5,7-dimethoxyanthraquinone** 4-*O*-*β*-D-glucopyranosyl-(1→4)-α-L-rhamnopyranoside	Sang et al. (2002)	Leaves	[c]Quercetin 3-*O*-α-L-rhamnopyranosyl-(1→6)-*β*-D-glucopyranoside	Sang et al. (2002)
Flower	5,8-dimethyl-apigenin 4′-*O*-*β*-D-galactopyranoside	Sang et al. (2002), Elkins (1998)	Leaves	Serine	Dittmar (1993), Elkins (1998)
Flower	**Aracetin** 7-*O*-*β*-D-glucopyranoside		Leaves	Threonine	Dittmar (1993), Elkins (1998)
Fruit	*β*-D-glucopyranose pentaacetate	Sang et al. (2002), Elkins (1998)	Leaves	Tryptophan	Dittmar (1993), Elkins (1998)
Fruit	2,6-di-*O*-(*β*-D-glucopyranosyl-1-*O*-octanoyl-*β*-D-glucopyranose	Dittmar (1993)	Leaves	Tyrosine	Dittmar (1993), Elkins (1998)
Fruit	6-*O*-(*β*-D-glucopyranosyl-1-*O*-octanoyl-*β*-D-glucopyranose	Wang et al. (1999)	Leaves	**Ursolic acid**	Sang et al. (2002), Cardon (2003), Elkins (1998), Wang et al. (2002)
Fruit	Ascorbic acid	Liu et al. (2001)	Leaves	Valine	Dittmar (1993), Elkins (1998
Fruit	**Asperulosidic acid**	Morton (1992), Elkins (1998), Wang et al. (2002), McClatchey (2002)	Plant	**2-methyl-3,5,6-trihydroxyanthraquinone**	Cardon (2003, Inoue et al. (1981)
Fruit	Asperuloside tetraacetate	Wang et al. (1999), Liu et al. (2001), Cardon (2003)	Plant	[b]2-methyl-3,5,6-trihydroxyanthraquinone 6-*O*-*β*-D-xylopyranosyl-(1→6)-*β*-D-glucopyranoside	Cardon (2003), Inoue et al. (1981)
Fruit	Caproic acid	Dittmar (1993)	Plant	**3-hydroxymorindone**	Cardon (2003), Inoue et al. (1981)
Fruit	Caprylic acid	Sang et al. (2002), Dittmar (1993), Elkins (1998), Wang et al. (2002), Levand and Larson (1979)	Plant	[b]3-hydroxymorindone 6-*O*-*β*-D-xylopyranosyl-(1→6)-*β*-D-glucopyranoside	Cardon (2003), Inoue et al. (1981)
Fruit	Ethyl caprylate	Solomon (1999), Dittmar (1993), Cardon (2003), Elkins (1998), Wang et al. (2002), Levand and Larson (1979)	Plant	[b]5,6-dihydorxylucidin 3-*O*-*β*-D-xylopyranosyl-(1→6)-*β*-D-glucopyranoside	Cardon (2003), Inoue et al. (1981)
Fruit	Ethyl caproate	Dittmar (1993)	Plant	**5,6-dihydroxylucidin**	Cardon (2003), Inoue et al. (1981)
Fruit	Hexanoic acid	Dittmar (1993)	Plant	**Aucubin**	Elkins (1998), Wang et al. (2002)
Fruit	Octanoic acid	Farine et al. (1996), Sang et al. (2002)	Plant	Linoleic acid	Wang et al. (2002)
Fruit	[c]Quercetin 3-*O*-α-L-rhamnopyranosyl-(1→6)-*β*-D-glucopyranoside	Farine et al. (1996), Sang et al. (2002), Cardon (2003), Wang and Su (2001)	Plant	**Lucidin**	Cardon (2003), Inoue et al. (1981), Ross (2001
Heartwood	**Physcion** 8-*O*-α-L-arabinopyranosyl-(1→3)-*β*-D-galactopyranosyl-(1→6)-*β* -D-galactopyranoside	Wang and Su (2001), Wang et al. (2002)	Plant	[b]Lucidin 3-*O*-*β*-D-xylopyranosyl-(1→6)-*β*-D-glucopyranoside	Cardon (2003, Inoue et al. (1981)
Leaves	Alanine	Sang et al. (2002), Srivastava and Singh (1993), Cardon (2003)	Plant	**Scopoletin**	Farine et al. (1996), Wang et al. (2002)

Leaves	Arginine	Dittmar (1993)	Root	**8-hydroxy-8-methoxy-2-methyl-anthraquinone**	Cardon (2003), Solomon (1999)
Leaves	Aspartic acid	Dittmar (1993)	Root	rubichloric acid	Elkins (1998), Morton (1992)
Leaves	β-sitosterol	Sang et al. (2002), Chunhieng (2003), Elkins (1998), Wang et al. (2002)	Root	**1,3-dihydroxy-6-methyl Anthraquinone**	Morton (1992)
Leaves	**Citrifolinoside B**	Sang et al. (2002)	Root	**Morenone 1**	Solomon (1999)
Leaves	Cysteine	Dittmar (1993), Elkins (1998)	Root	**Morenone 2**	Solomon (1999)
Leaves	Cystine	Dittmar (1993), Elkins (1998)	Root	[b]**Ruberythric acid**	Cardon (2003)
Leaves	Glutamic acid	Dittmar (1993)	Root	**Rubiadin**	Cardon (2003), Elkins (1998), Inoue et al. (1981), Ross (2001)
Leaves	Glycine	Dittmar (1993), Elkins (1998)	Root bark	Chlororubin	Dittmar (1993), Elkins (1998)
Leaves	Histidine	Dittmar (1993), Elkins (1998)	Root bark	Hexose	Dittmar (1993)
Leaves	Isoleucine	Dittmar (1993), Elkins (1998)	Root bark	Morindadiol	Dittmar (1993)
Leaves	[c]Kaempferol 3-*O*-α-L-rhamnopyranosyl-(1→6)-β-D-glucopyranoside	Sang et al. (2002)	Root bark	**Morindanidrine**	Dittmar (1993)
Leaves	Kaempferol 3-*O*-β-D-glucopyranosyl-(1→2)-α-L-rhamnopyranosyl-(1→6)-β-D-galactopyranoside	Sang et al. (2002)	Root bark	**Morindine**	Cardon (2003), Dittmar (1993), Elkins (1998), Morton (1992)
Leaves	Leucine	Dittmar (1993), Elkins (1998)	Root bark	Pentose	Dittmar (1993)
Leaves	Methionine	Dittmar (1993), Elkins (1998)	Root bark	**Physcion**	Solomon (1999)
Leaves	Phenylalanine	Dittmar (1993), Elkins (1998)	Root bark	**Rubiadin monomethyl ether**	Dittmar (1993)
Leaves	Proline	Dittmar (1993), Elkins (1998)	Root bark	**Soranjidiol**	Dittmar (1993), Elkins (1998), Ross (2001v
Leaves	Quercetin 3-*O*-β-D-glucopyranoside	Sang et al. (2002)	Root bark	Trioxymethylanthraquinone monoethyl ether	Dittmar (1993)
Root, heartwood, root bark	**Morindone**	Sang et al. (2002), Inoue et al. (1981), Dittmar (1993), Ross (2001), Cardon (2003), Wang et al. (2002)	Root, root bark, fruit	**Alizarin**	Cardon (2003), Dittmar (1993), Elkins (1998), Ross (2001), Wang et al. (2002)
Root, heartwood, seeds	**Damnacanthal**	Sang et al. (2002), Cardon (2003)	Seeds	Ricinoleic acid	Solomon (1999)
Leaves	Quercetin 3-*O*-β-D-glucopyranosyl-(1→2)-α-L-rhamnopyranosyl-(1→6)-β-D-galactopyranoside	Sang et al. (2002)			

[a]Molecules in bold are presented in Fig. 1.
[b]These glycosides are primeverosides [= *O*-β-D-xylopyranosyl-(1→6)-β-D-glucopyranosides].
[c]These glycosides are rutinosides [= *O*-α-L-rhamnopyranosyl-(1→6)-β-D-glucopyranosides].

Table 3
Physico-chemical composition of noni juice

Characteristics	Chunhieng (2003)[a]	Shovic and Whistler (2001)[a]	European Commission (2002)[b]
pH-value	3.72	—	3.4–3.6
Dry matter	9.8 ± 0.4%	—	10–11%
Total soluble solids (°Brix)	8	—	—
Protein content	2.5%	0.4 g/100 g	0.2–0.5%
Lipid	0.15%	0.30 g/100 g	0.1–0.2%
Glucose	11.9 ± 0.2 g/l	—	3.0–4.0 g/100 g
Fructose	8.2 ± 0.2 g/l	—	3.0–4.0 g/100 g
Potassium	3900 mg/l	188 mg/100 g	30–150 mg/100 g
Sodium	214 mg/l	21 mg/100 g	15–40 mg/100 g
Magnesium	14 mg/l	14.5 mg/100 g	3–12 mg/100 g
Calcium	28 mg/l	41.7 mg/100 g	20–25 mg/100 g
Vitamin C	—	155 mg/100 g	3–25 mg/100 g

[a]Noni fruit.
[b]Tahitian Noni™ Juice (Commercial noni juice that contain 89% noni juice and 11% common grape and blueberry juice concentrates).

5.3. Anti-oxidant properties

The anti-oxidant properties of ethanol and ethyl acetate extracts of noni fruit have been assessed using the ferric thiocyanate method (FTC) and thiobarbituric acid test (TBA). The authors found that ethyl acetate extract exhibited strong inhibition of lipid oxidation comparable to the same weight of pure α-tocopherol and butylated hydroxy toluene (BHT) (Mohd et al., 2001).

Radical scavenging activity was also measured in vitro by the tetrazolium nitroblue (TNB) assay on a commercial juice, by assessing the potential capacity of the juice to protect cells or lipids from oxidative alteration promoted by superoxide anion radicals (SAR). The SAR scavenging activity of noni juice was shown to be 2.8 times higher than that of vitamin C, 1.4 times that of pycnogenol (PYC) and almost of the same order as that of grape seed powder. (Wang and Su, 2001).

5.4. Anti-inflammatory activity

The anti-inflammatory activity of an aqueous extract from noni juice was observed by inducing a locally acute inflammatory response, with the help of a pro-inflammatory agent (bradykinin). It was shown that the oral administration of a noni juice extract (200 mg) quite rapidly inhibited the formation of rat paw edema. This effect may have resulted from interference with the B2 receptor-mediated mechanism by which bradykinin induces rat paw edema (McKoy et al., 2002).

Another study showed that commercial noni juice has a selective inhibition effect on some cyclo-oxygenase enzymes (COX-1 and COX-2) involved in breast, colon and lung cancer, and also in anti-inflammatory activity (Su et al., 2001). The inhibition of the activity of these enzymes by noni juice was compared with that of commercial traditional non-steroidal inflammatory drugs such as aspirin, Indomethacin® and Celebrex®. Noni juice showed selective inhibition of COX enzyme activity in vitro and a strong anti-inflammatory effect comparable to that of Celebrex® and presumably without side effects.

5.5. Analgesic activity

Recent research examined the analgesic properties of a commercial juice in rats. The results showed that rats fed with 10% and 20% noni juice had greater pain tolerance (162% and 212%, respectively) compared with the placebo group (Wang et al., 2002). A French research team has also studied the analgesic and sedative effects of noni on mice through the writhing and hotplate tests. Noni root extract (1600 mg/kg) showed significant analgesic activity in the animals, similar to the effect of morphine (75% and 81% protection using noni extract and morphine, respectively), and it also proved to be non-toxic (Younos et al., 1990).

5.6. Cardiovascular activity

Recent research has demonstrated the effects of noni fruit on preventing arteriosclerosis, a disease related to the oxidation of low density lipoproteins (LDL). Methanol and ethyl acetate extracts showed with the thiobarbituric acid reactive substance method 88 and 96% inhibition, respectively, of copper-induced LDL oxidation. This beneficial effect could be due to the presence of lignans, phenylpropanoid dimers (Kamiya et al., 2004).

6. Conclusion

The *Morinda citrifolia* plant, and especially its fruit, has been used for centuries in folk medicine. Different studies, some of them with controversial methodologies, showed that this fruit contains several nutritional and functional compounds, but most of them have not been quantified.

The most important compounds identified in noni fruit are phenolics, such as damnacanthal and scopoletin, organic acids (caproic and caprylic acid), vitamins (ascorbic acid and provitamin A), amino acids such as aspartic acid, and minerals. Another compound named xeronine, supposedly an alkaloid, has been reported but its structure never published. On the other hand, scientific studies have opened some interesting doors, but most have not conclusively proved the nutritional or medical value of this plant. The main proven functional properties of noni fruit are related to the control of several diseases. In vitro research and limited experiments with lab animals have shown that noni has anti-microbial, anti-cancer, anti-oxidant, anti-inflammatory, analgesic and cardiovascular activity.

The current market, basically centering on the Polynesian noni, and more specifically the Tahitian one, has conferred upon the fruit a unique and authentic appeal. Other countries may in the future decide to launch noni production and supplant the original producers. Market interest in this fruit suggests a bright future, although more studies are needed to identify the nutritional and functional compounds it contains and explain their mechanisms of action in order to determine the real potential of this fruit and the technological processes that preserve these properties.

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References

Atkinson, N., 1956. Antibacterial substances from flowering plants. 3. Antibacterial activity of dried Australian plants by rapid direct plate test. Australian Journal of Experimental Biology 34, 17–26.

Bushnell, O.A., Fukuda, M., Makinodian, T., 1950. The antibacterial properties of some plants found in Hawaii. Pacific Science 4, 167–183.

Cardon, D., 2003. Le Monde des Teintures Naturelles. Belin, Paris.

Chunhieng, M.T., 2003. Développement de nouveaux aliments santé tropicale: application à la noix du Brésil Bertholettia excelsa et au fruit de Cambodge Morinda citrifolia. Ph.D. thesis, INPL, France.

Dittmar, A., 1993. *Morinda citrifolia* L.—Use in indigenous Samoan medicine. Journal of Herbs, Spices and Medicine Plants 1, 77–92.

Dixon, A.R., McMillen, H., Etkin, N.L., 1999. Ferment this: the transformation of Noni, a traditional Polynesian medicine (Morinda citrifolia, Rubiaceae). Ecological Botony 53, 51–68.

Duncan, S.H., Flint, H.J., Stewart, C.S., 1998. Inhibitory activity of gut bacteria against *Escherichia coli* O157 mediated by dietary plant metabolites. FEMS Microbiology Letters 164, 258–283.

Earle, J.E., 2001. Plantas Medicinales en el Trópico Húmedo. Editorial Guayacán, San José.

Elkins, R., 1998. Hawaiian Noni (Morinda citrifolia) Prize Herb of Hawaii and the South Pacific. Woodland Publishing, Utah.

European Commission. Scientific Committee of Food, 2002. Opinion of the Scientific Committee on Food of Tahitian Noni® Juice. SCF/CS/DOS/18 ADD 2. Belgium.

Farine, J.P., Legal, L., Moreteau, B., Le Quere, J.L., 1996. Volatile components of ripe fruits of *Morinda citrifolia* and their effects on Drosophila. Phytochemistry 41, 433–438.

Heinicke, R.M., 1985. The pharmacologically active ingredient of Noni. Bulletin of the National Tropical Botanical Garden 15, 10–14.

Hiramatsu, T., Imoto, M., Koyano, T., Umezawa, K., 1993. Induction of normal phenotypes in RAS transformed cells by damnacanthal from *Morinda citrifolia*. Cancer Letters 73, 161–166.

Hirazumi, A., Furusawa, E., 1999. An immunomodulatory polysaccharide-rich substance from the fruit juice of *Morinda citrifolia* (Noni) with antitumor activity. Phytotherapic Research 13, 380–387.

Hirazumi, A., Furusawa, E., Chou, S.C., Hokama, Y., 1994. Anti cancer activity of *Morinda citrifolia* on intraperitoneally implanted Lewis lung carcinoma in syngenic mice. Proceedings of the Western Pharmacological Society 37, 145–146.

Hirazumi, A., Furusawa, E., Chou, S.C., Hokama, Y., 1996. Immunomodulation contributes to the anticancer activity of *Morinda citrifolia* (Noni) fruit juice. Proceedings of the Western Pharmacological Society 39, 7–9.

Inoue, K., Nayeshiro, H., Inouye, H., Zenk, M., 1981. Anthraquinones in cell suspension culture of Morinda citrifolia. Phytochemistry 20, 1693–1700.

Kamiya, K., Tanaka, Y., Endang, H., Umar, M., Satake, T., 2004. Chemical constituents of *Morinda citrifolia* fruits inhibit copper-induced Low-Density Lipoprotein oxidation. Journal of Agriculture and Food Chemistry 52, 5843–5848.

Levand, O., Larson, H.O., 1979. Some chemical constituents of Morinda citrifolia. Planta Medica 36, 186–187.

Liu, G., Bode, A., Ma, W.Y., Sang, S., Ho, C.T., Dong, Z., 2001. Two novel glycosides from the fruits of *Morinda citrifolia* (Noni) inhibit AP-1 transactivation and cell transformation in the mouse epidermal JB6 cell line. Cancer Research 61, 5749–5756.

Locher, C.P., Burch, M.T., Mower, H.F., Berestecky, H., Davis, H., Van Polel, B., Lasure, A., Vander Berghe, D.A., Vlieti-Nick, A.J., 1995. Anti-microbial activity and anti-complement activity of extracts obtained from selected Hawaiian medicinal plants. Journal of Ethnopharmacology 49, 23–32.

Lüberck, W., Hannes, H., 2001. Noni. El Valioso Tesoro Curativo de Los Mares del Sur. Editorial EDAF S.A., Madrid.

McClatchey, W., 2002. From Polynesian healers to health food stores: changing perspectives of *Morinda citrifolia* (Rubiaceae). Integral Cancer Therapy 1, 110–120.

McKoy, M.L.G., Thomas, E.A., Simon, O.R., 2002. Preliminary investigation of the anti-inflammatory properties of an aqueous extract from *Morinda citrifolia* (Noni). Pharmacological Society 45, 76–78.

Mohd, Z., Abdul-Hamid, A., Osman, A., 2001. Antioxidative activity extracts from Mengkudu (*Morinda citrifolia* L.) root, fruit and leaf. Food Chemistry 78, 227–231.

Morton, J.F., 1992. The ocean-going Noni, or Indian mulberry (Morinda citrifolia, Rubiaceae) and some of its "colourful" relatives. Ecological Botony 46, 241–256.

Nelson, S.C., 2001. Noni cultivation in Hawaii. Fruit and Nuts 4, 1–4.

Nelson, S.C., 2003. Noni Cultivation and Production in Hawaii. In: Proceedings of the 2002 Hawaii Noni Conference. University of Hawaii at Nanoa. College of Tropical Agriculture and Human Resources. Hawaii.

Ross, I.A., 2001. Medical Plants of the World. Chemical Constituents, Traditional and Modern Medical Uses. Humana Press, New Jersey.

Saludes, J.P., Garson, M.J., Franzblau, S.G., Aguinaldo, A.M., 2002. Antitubercular constituents from the hexane fraction of *Morinda citrifolia* L. (Rubiaceae). Phytotherapic Research 16, 683–685.

Sang, S., Cheng, X., Zhu, N., Stark, R.E., Badmaev, V., Ghai, G., Rosen, R., Ho, C.T., 2001. Flavonol glycosides and novel iridoid glycoside

from the leaves of Morinda citrifolia. Journal of Agriculture and Food Chemistry 49, 4478–4481.

Sang, S., Wang, M., He, K., Liu, G., Dong, Z., Badmaev, V., Zheng, Q.Y., Ghai, G., Rosen, R.T., Ho, C.T., 2002. Chemical components in Noni fruits and leaves (*Morinda citrifolia* L.). In: Ho, C.T., Zheng, Q.Y. (Eds.), Quality Management of Nutraceuticals. ASC Symposium Series 803, American Chemistry Society, Washington, DC, pp. 134–150.

SHOVIC, A.C., Whistler, W.A., 2001. Food sources of provitamin A and vitamin C in the American Pacific. Tropical Science 41, 199–202.

Solomon, N., 1999. The Noni Phenomenon. Direct Source Publishing, Utah.

Srivastava, M., Singh, J., 1993. A new anthraquinone glycoside form Morinda citrifolia. Journal of Pharmacology 31, 182–184.

Su, C., Wang, M., Nowicki, D., Jensen, J., Anderson, G., 2001. Selective COX-2 inhibition of *Morinda citrifolia* (Noni) in vitro. In: The Proceedings of the Eicosanoids and other Bioactive Lipids in Cancer, Inflammation and Related Disease. The 7th Annual Conference, 2001 October 14–17. Loews Vanderbilt Plaza, Nashville, Tennessee, USA.

USPTO, 2005. Patent Full-Text and Image Database. Patents (Morinda citrifolia). Retrieved January 17, 2005 from the World Wide Web: http://patft.uspto.gov/netacgi/nph.

Wang, M.Y., Su, C., 2001. Cancer preventive effect of *Morinda citrifolia* (Noni). Annals of the New York Academy of Sciences 952, 161–168.

Wang, M., Kikuzaki, K.C., Boyd, C.D., Maunakea, A., Fong, S.F.T., Ghai, G.R., Rosen, R.T., Nakatani, N., Ho, C.T., 1999. Novel trisaccharide fatty acid ester identified from the fruits of *Morinda citrifolia* (Noni). Journal of Agriculture and Food Chemistry 47, 4880–4882.

Wang, M.Y., West, B., Jensen, C.J., Nowicki, D., Su, C., Palu, A.K., Anderson, G., 2002. *Morinda citrifolia* (Noni): a literature review and recent advances in Noni research. Acta. Pharmacologica Sinica. 23, 1127–1141.

Younos, C., Rolland, A., Fleurentin, J., Lanhers, M.C., Misslin, R., Mortier, F., 1990. Analgesic and behavioral effects of Morinda citrifolia. Planta Medicine 56, 430–434.