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Review

Arrowroot (*Maranta arundinacea* L.) as a new potential functional food: A scoping review

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Abstract

Maranta arundinacea L. (MA) is a food that contains phytochemicals such as phenols, saponins, and flavanones that are beneficial to the body. Several studies have also reported that MA contains soluble fibre. These indicate its potential use to prevent and treat diseases. The present review explored the literature on the potential benefits of MA. Published MA-related studies were searched for up to October 2018 using the PubMed, ProQuest, EBSCO, and Scopus databases, as well as Google Scholar up to October 2020. The keywords used were '*Maranta arundinacea*' OR 'arrowroot' OR 'maranta' OR 'West Indian arrowroot' OR 'obedience plant' OR 'Bermuda arrowroot' OR '*araru*' OR '*ararao*' OR '*hulankeeriya*' OR 'Marantaceae' OR '*garut*' OR '*ararut*' OR '*irut*'. The present review included ten *in vitro* studies, nine of which involved experimental animals, and eight studies in humans. *In vitro* and *in vivo* studies in animals show that MA has antioxidative, anti-inflammatory, prebiotic, antibacterial, immunomodulatory, anti-ulcerative, anti-diarrhoeal, hypoglycaemic, hypocholesterolaemic, and antihypertensive properties. However, studies involving humans were quasi experimental, without control and non-randomised, with a small number of subjects. The results of human studies have not shown a significant change in health effects. In the future, MA may increase food diversity by serving as a functional foodstuff. However, additional human research must be conducted.

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Introduction

People in certain regions have long consumed *Maranta arundinacea* L. (MA), and used it as a remedy, *e.g.* as a snakebite antidote (Mansoor and Sanmugarajah, 2018). Ancient Mayan tribes and Central American peoples have also used it as a poison antidote (Shintu *et al.*, 2015). In Mauritius, MA root powder is used to treat diarrhoea in children and adults (Mahomoodally, 2014; Mahomoodally and Sreekeesoon, 2014). It is even reported that a society on the Amazonian coast of Marudá, in the state of Pará in Brazil, use the plant as an indicator for tuberculosis and lethargy (Coelho-Ferreira, 2009). The MA bulbs can also increase iron (III) solubility, thus providing support for the application of this component as an alternative therapy for iron-deficiency anaemia (Mophan *et al.*, 2010). Accordingly, MA has the potential for being developed as alternative medicine.

The MA tubers are high in carbohydrates, thus reflecting its potential as an alternative to staple foods such as rice and wheat (Amalia, 2014). The starch of the plant is digestible to both infants and adults experiencing indigestion (Faridah *et al.*, 2014). When combined with soy or pumpkin, MA flour can be developed as a complementary food for infants (Aini and Wirawan, 2014). The starch of MA thus has the potential for being developed and modified as a raw or additional material for food, and use in non-food

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industries (Jyothi *et al.,* 2009; Piriyaprasarth *et al.,* 2010; Builders and Arhewoh, 2016).

The MA tubers contain phytochemicals indicating antioxidant activity (Ruba and Mohan, 2013). Antioxidants fight free radicals that can initially trigger several human diseases. A study on MA tuber flour also found it to be rich in fibre, including 2.37% soluble and 12.49% insoluble fibres (Harmayani *et al.,* 2011). The presence of fibres and antioxidants in MA holds significant potential for the development of functional foods. However, the effects of this need to be proven through valid research ranging from pre-clinical trials in animals to clinical trials in humans.

Functional foods should not have dangerous or toxic effects. Functional food for disease prevention is currently being developed because it is safer, easier, and cheaper than drug consumption (Martirosyan and Singh, 2015). Existing research needs to be collected and documented for acceptance by public. If MA can be an alternative diet option, drug use can be reduced. The use of drugs often causes side-effects because it can give rise to a homeostatic imbalance as compared to food (Witkamp and Norren, 2018).

In Brazil, MA production remains limited (de Oliveira Guilherme *et al.,* 2017), and in Indonesia, not all regions cultivate this plant (Djaafar *et al.,* 2010). Proving the benefits of MA is expected to officially increase the market of this plant. For the market to increase, the legal authorisation of health claims is needed. Furthermore, promoting the development and promotion of further cultivation of MA can have consequences for policymakers. Therefore, by evaluating the existing research, the present review aims to establish the degree to which MA can currently be used to prevent and treat diseases. The present review also discusses the mechanisms underlying the ability of MA as a functional food.

Materials and methods

The present review was conducted by effecting systematic searches in the PubMed, EBSCOhost, Cochrane Library, Scopus, and ProQuest databases. The article searches used keywords including '*Maranta arundinacea'* OR 'arrowroot' OR '*maranta*' OR 'West Indian arrowroot' OR 'obedience plant' OR 'Bermuda arrowroot' OR '*araru*' OR '*ararao*' OR '*hulankeeriya*' OR 'Marantaceae' OR '*garut*' OR '*ararut*' OR '*irut*' listed in papers published up to October 2018. The literature search was continued from November 2018 to October 2020 using Google Scholar.

Article selection was based on the following criteria: (1) included the common name arrowroot and scientific name *Maranta Arundinacea* L.; (2) reported the health benefits of arrowroot; (3) was conducted *in vitro*, *in vivo*, or involving human participants; and (4) only included MA tubers or rhizomes because these are what people typically consume. The exclusion criteria were for articles that: (1) discussed arrowroot types other than MA; (2) did not discuss the health benefits of MA; (3) discussed arrowroot with several modifications or in combination with other herbs; (4) were not available as full texts; (5) were published in languages other than English and Indonesian. Based on these criteria, selection started from the titles, then abstracts, and thirdly based on the full text. From the obtained full texts, the search continued according to their references, starting from the titles and abstracts, and then the full texts were selected based on the criteria fulfilment (Figure 1).

Of the 27 selected articles, the bulk of MA studies were based in Indonesia followed by India; one article each was from Taiwan and the United Kingdom. There were 10 *in vitro* studies, nine *in vivo* studies involving experimental animals, and eight human studies (Table 1). *In vitro* studies showed MA to have antioxidant, anti-inflammatory, prebiotic, and antibacterial properties. *In vivo* studies on animals indicated immunomodulatory, prebiotic, anti-ulcerative, anti-diarrhoeal, hypoglycaemic, hypocholesterolaemic, and antihypertensive properties. Unfortunately, none of the studies indicated the potential of MA for human use. The results of studies on MA for human use varied, and were also limited to a small number of subjects, without control and non-randomisation.

Maranta arundinacea

Maranta arundinacea is a local plant in many tropical countries including Indonesia, Sri Lanka, the Philippines, India, and Australia. This plant is taxonomically classified in the kingdom Plantae, sub-kingdom Tracheophyta, division Magnoliophyta, class Liliopsida, sub-class Zingiberidae, order Zingiberales, family Marantaceae, genus *Maranta*,

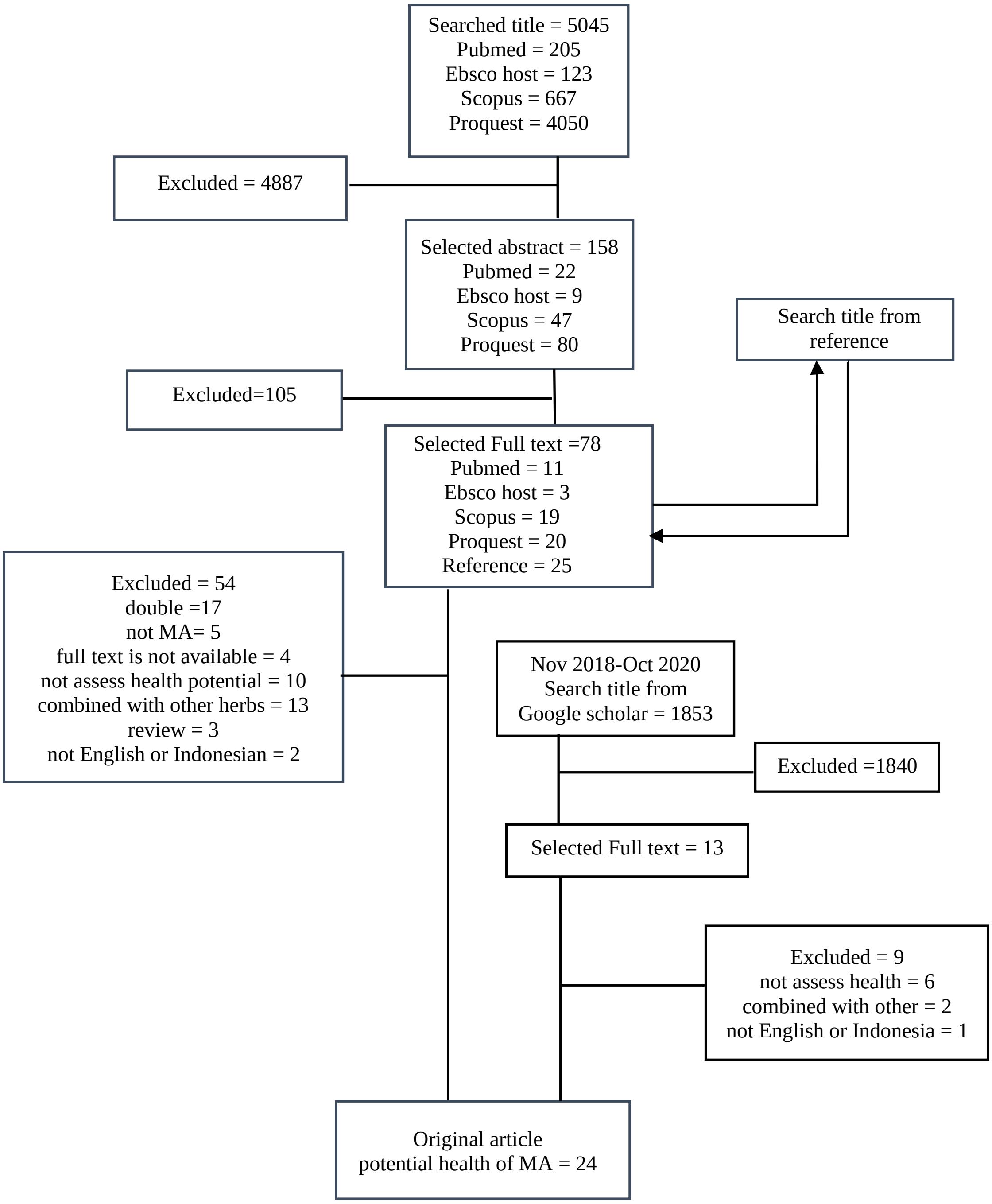

Figure 1. Article search.

Table 1. Studies related to MA health potentials.

Rhizome or tuber of MA	**Country**	**Type of test**	**Activity**	**Result**	**Reference**
Methanolic extract	India	*In vitro*	Antioxidant	>> Compared to standard antioxidant (vitamin C and Trolox) against DPPH and ABTS	Ruba and Mohan (2013)
Ethanolic extract	India	*In vitro*	Antioxidant	Equivalent to BHT standard against DPPH, ABTS, hydrogen peroxide, and nitric oxide radicals	Nishaa *et al*. (2012)
Tuber and leaf	Indonesia	*In vitro*	Antioxidant	Fresh leaf >> fresh tuber	Kusbandari and SuSanti (2017)
Made into a membrane	Taiwan	*In vitro*	Antioxidant and cytocompatibility	Compared to membrane from PHA, concentration of polyphenol >> (S), antioxidant >> (S), fibroblast cell viability >> (S)	Wu and Liao (2017)
Ethanolic extract	Indonesia	*In vivo*, rats	Antioxidant	MDA, SGOT, SGPT level << control (S)	Ramadhani *et al*. (2017)
Ethanolic extract powdered raw	India	*In vitro*	Antioxidant and anti-inflammatory	Anti-inflammatory activity >> *Mesua ferrea*, *Zingiber officinale*, and *Syzygium aromaticum*	Rajalakshmi *et al*. (2016)
MA powder mediated selenium nanoparticles	India	*In vitro*	Anti-inflammatory	Anti-inflammatory activity = diclofenac	Francis *et al.* (2020)
Ethanolic extract	Indonesia	*In vivo*, rats	Prebiotic	After 10 days, number of *E. coli* ↓ and LAB ↑ vs control	Dwiari (2008)
Sugar extract of arrowroot tuber flour	Indonesia	*In vitro*	Prebiotic	Number of *Salmonella*, *E. coli*, and *B. cereus* ↓ when compared with *Lactobacillus G3* and *B. bifidum*	Krisnayudha (2007)
Tuber powder	Indonesia	*In vivo*, rats	Prebiotic	Compared to AIN93M, *Lactobacillus* >> (S), *Bifidobacterium* >> (NS), *E. coli* << (NS), *C. perfringens* << (NS), SCFA (butyrate) >> gastric pH << (S)	Harmayani *et al.* (2011)
Extract	India	*In vitro*	Antibacterial	At 250 µL: zone of inhibition 6.1 mm in *E. coli* and 2.5 mm in *S. aureus*	Rokhade and Taranath (2018)
MA for selenium nanoparticle	India	*In vitro*	Antibacterial	Inhibition of *Streptococcus mutans* and lactobacillus >> control	Balamithra *et al.* (2020)
Methanolic extract	Indonesia	*In vitro*	Antibacterial	Inhibition 15.88 mm in methicillin-resistant *S. aureus*	Syahputra *et al*. (2020)
Tuber extract	Indonesia	*In vitro*, mouse splenocyte cell	Immunomodulator	IgG, IgM, IgA >> control water	Kumalasari *et al.* (2012)
Tuber powder	Indonesia	*In vivo*, BALB/c mice	Immunomodulator	IgM, IgG, IgA >> (S) AIN-93M	Kumalasari *et al*. (2012)

Tuber cookies 30 g/day	Indonesia	QE, 17 children (2 - 5 years old)	Immunomodulator	After 20 days: IgA in faeces ↑ (NS), faecal moisture ↑ (S), pH ↓ (NS)	Nurliyani *et al.* (2013)
Rhizome starch	India	*In vivo*, rats	Anti-ulcerative	1,100 mg/kg body weight causing gastric juice << (S), gastric pH >> (S), peptic activity << (S), total carbohydrates >> (S), gastric mucosa histology was better than that of the control	Rajashekhara *et al.* (2014)
Rhizome starch	India	QE, 33 patients with dyspepsia	Antidyspeptic	4 g, three times a day, complete remission (1/33), marked improvement (26/33), moderate improvement (6/33)	Rajashekhara and Sharma (2010)
Tuber powder 5 mL	UK	QE, 11 patients IBS	Antidiarrheal	One patient felt complete benefit, five patients with moderate improvement, abdominal pain << (S), daytime frequency of defecation << (S), one patient developed dyspepsia, one patient constipated	Cooke *et al.* (2000)
Rhizome	Indonesia	QE, 10 healthy individuals	Hypoglycaemic	Compared to plain bread: low IG value (14)	Marsono (2002)
Rhizome	Indonesia	QE, 10 healthy individuals	Hypoglycaemic	Compared to pure glucose, low IG value (32)	Utami (2008)
Tuber infusion	Indonesia	*In vivo*, 30 Wistar rats	Hypoglycaemic	Blood glucose ↓ (S), plasma insulin ↑ (S)	Yuniastuti *et al.* (2018)
Tuber analog rice	Indonesia	*In vivo*, 30 SD rats	Hypoglycaemic	Blood glucose ↓, pancreatic histopathology	Pricilla and Buana (2020)
Crispy flakes of MA tuber, 20 g/day	Indonesia	QE, 15 patients with T2DM	Anthropometry	After four weeks: BW ↓ (S), BMI ↓ (S), fasting glucose ↑ (NS), SOD ↓ (S), NO ↓ (NS), triglyceride ↑ (S), total cholesterols ↓ (NS)	Prastuti and Sunarti (2012)
Rhizome butyrylated starch	Indonesia	*In vivo*, 36 rats	Hypocholesterolaemic	Total cholesterol << (S), LDL-C << (S), triglyceride << (S), HDL-C >> (S)	Damat (2012)
Tuber crispy flakes, 21 g/day	Indonesia	QE, 30 T2DM patients	Anthropometry	After eight weeks: BW ↓ (NS), WC ↓ (NS), plasma free fatty acid ↑ (NS)	Sunarti *et al.* (2014)
Crispy flakes of arrowroot tuber, 20 g/day	Indonesia	QE, 15 patients with T2DM	Antihypertensive	After four weeks: angiotensin II ↓ (NS), systolic ↓ (NS), diastolic ↓ (NS)	Novitasari *et al.* (2011)
Tuber analog rice	Indonesia	*In vivo*, Wistar rat	Antihypertensive	Systolic blood pressure ↓ vs. IR36v rice	Estiasih *et al.* (2016)

(<<): lower, (>>): higher, (↑): increase, (↓): decrease, S: significant, NS: insignificant, vs.: versus, ABTS: 2,2’-azinobis-3-ethylbenzothiozoline-6-sulfonic acid, BHT: butylated hydroxyl toluene, BMI: body mass index, BW: body weight, DPPH: 1-diphenyl-2-picryl-hydrazyl, IBS: irritable bowel syndrome, QS: quasi experimental, PHA: polyhydroxyalkanoates, LAB: lactic acid bacteria, NO: nitric oxide; SCFA: short chain fatty acid, SOD: superoxide dismutase; T2DM: type 2 diabetes mellitus.

and species *M. arundinacea* L. Its local names include arrowroot, West Indian arrowroot, obedience plant, Bermuda arrowroot, *araru*, *ararao*, *hulankeeriya*, *garut*, *ararut*, and *irut* (Chandrasekara and Kumar, 2016). Although widely known as arrowroot, not all arrowroots are derived from MA. *Maranta arundinacea* is a tropical herbaceous plant with a long, thin, small stem, and cream-coloured stripes. The flowers are cream in colour and grow as twin clusters (Shintu *et al.*, 2015). Growing to a height of approximately 1 to 1.5 m, MA has abundant leaves that are ovate to lanceolate in shape, and sized between 2 and 10 inches. It produces fleshy rhizomes underground with a cylindrical shape, scar rings, and large, thin scales (Miftakhussolikhah *et al.*, 2016).

Nutritional content

Maranta arundinacea contains important nutrients for the body such as carbohydrates, proteins, fats, vitamins, and minerals (USDA, 2018). Different types of foods use MA tuber, flour, and starch, which have different compositions; however, MA is well known for its high carbohydrate and fibre contents (Table 2).

Antioxidative and anti-inflammatory properties

The ethanolic extract of MA tuber effects antioxidant activity *in vitro* against free radicals, including 1-diphenyl-2-picryl-hydrazyl (DPPH), 2,2’-azinobis-3-ethylbenzothiozoline-6-sulfonic acid (ABTS), hydrogen peroxide, and nitric oxide radicals with 293.4, 297.4, 336.1, and 258.7 µg/mL inhibitory concentrations (IC_{50}), respectively. The percentage of activity was similar to that of butylated hydroxyl toluene standard antioxidant (Nishaa *et al.*, 2012). One study indicated that the methanolic extract of MA tuber had higher antioxidant properties against DPPH free radicals *in vitro* when compared with vitamin C, and against ABTS free radicals when compared with Trolox (an antioxidant equivalent to vitamin E), despite its IC_{50} being higher than vitamin C and Trolox (Ruba and Mohan, 2013). In ethanol-induced liver injury rats, malondialdehyde, as a biomarker of oxidative stress, and serum glutamic oxaloacetic transaminase and serum glutamic pyruvic transaminase, as biomarkers of hepatic cell damage were lower in concentrations in the blood when compared with those of negative control rats. This indicated the ability of MA tuber extract to reduce oxidative stress, thereby minimising damage to hepatic cells (Ramadhani *et al.*, 2017). However, a study of 14 patients with type 2 diabetes (T2DM) consuming 20 mg of MA crispy flakes per day as a snack showed no increase in the concentration of superoxide dismutase antioxidant enzyme which catalyses the change of superoxide ion free radicals into hydrogen peroxide. The study also found no changes in nitric oxide (NO), where increased NO can limit inflammation and prevent atherosclerosis (Prastuti and Sunarti, 2012).

The properties described above are derived from MA tubers which contain several phytochemical components. The methanolic extract of MA tubers includes alkaloids, carbohydrates, cardiac glycosides, proteins, amino acids, phenolic compounds, terpenoids, saponins, flavones, flavanones, tannins, and gums (Nishaa *et al.*, 2013; Shintu *et al.*, 2015). Chloroform and petroleum ether extract of MA tubers contain cardiac glycosides, sterols, and saponins. Aqueous extracts contain carbohydrates, cardiac glycosides, phenolic compounds (Shintu *et al.*, 2015), alkaloids, terpenes, saponins, phenols (Jayakumar and Suganthi, 2017), and resins (Rajashekhara *et al.*, 2013). Phenolic compounds can donate their hydroxyl groups to free radicals, thus neutralising and absorbing them. Flavonoids can stabilise reactive oxygen to render free radicals inactive, and can scavenge superoxides to prevent cellular injury and inflammation (Panche *et al.*, 2016). The ethanolic extract of powdered raw MA has anti-inflammatory properties which have been proven by an increase in the membrane stabilisation of red blood cells (Rajalakshmi *et al.*, 2016). The anti-inflammatory properties of MA root-mediated selenium nanoparticles have been observed when compared with the standard diclofenac (Francis *et al.*, 2020). Additionally, T2DM patients who consumed an average 1,500 kcal diet, and between meals ate a snack comprising MA, yam (*Dioscorea esculenta*), cassava (*Manihot esculenta*), and pumpkin (*Cucurbita pepo*) as much as 32 g per day for four weeks may experience a significant decrease in C-reactive protein (CRP) concentration (Sunarti *et al.*, 2018). Moreover, CRP is one of the biomarker proteins in acute inflammation. Its concentration can reach a 1,000-fold increase in inflammation or infection areas (Sproston and Ashworth, 2018).

Table 2. Nutritional content of MA (USDA, 2018).

Nutrient	Unit	MA flour (per 100 g)	MA, raw (per 100 g)
Water	g	11.37	80.75
Energy	kcal	357	65
Protein	g	0.3	4.24
Total lipid (fat)	g	0.1	0.2
Carbohydrate	g	88.15	13.39
Fibre	g	3.4	1.3
Calcium (Ca)	mg	40	6
Iron (Fe)	mg	0.33	2.22
Magnesium (Mg)	mg	3	25
Phosphorus (P)	mg	5	98
Potassium (K)	mg	11	454
Sodium (Na)	mg	2	26
Zinc (Zn)	mg	0.07	0.63
Vitamin A (RAE)	µg	0	1
Vitamin A (IU)	IU	0	19
Vitamin B_1 (thiamine)	mg	0.001	0.143
Vitamin B_2 (riboflavin)	mg	0.0	0.059
Vitamin B_3 (niacin)	mg	0.0	1.693
Vitamin B_6 (pyridoxin)	mg	0.005	0.266
Vitamin B_9 (folate)	µg	7	338
Vitamin B_{12} (cobalamin)	µg	0.00	0.00
Vitamin C (total ascorbic acid)	mg	0.0	1.9
Vitamin D (D_2+D_3)	µg	0.0	0.00
Vitamin D	IU	0	0
Fatty acid, total saturated	g	0.019	0.039
Fatty acid, total monounsaturated	g	0.002	0.004
Fatty acid, total polyunsaturated	g	0.045	0.0092
Cholesterol	mg	0	0

Prebiotic and antibacterial properties

Silver nanoparticles prepared from MA rhizome extract inhibited the growth of *Staphylococcus aureus* and *Escherichia coli in vitro* (Rokhade and Taranath, 2018). Selenium nanoparticles from MA inhibited *Streptococcus mutans* and *Lactobacillus* (Balamithra *et al.*, 2020). Additionally, the methanolic extract of MA inhibited methicillin-resistant *Staphylococcus aureus* (Syahputra *et al.*, 2020). The growth of *E. coli*, *Salmonella*, and *Bacillus cereus* was reduced by 3.2, 1.5 - 3.9, and 1.4 - 3.5 log CFU/mL, respectively, when compared to *Lactobacillus casei* rhamnosus strain in media containing MA extract (Dwiari, 2008).

An *in vivo* study of rats consuming an AIN-93-modified diet with MA flour as a substitute for corn starch found that the *Clostridium perfringens* and *E. coli* populations in these rats were lower as compared to the control group with an AIN-93M diet, although the difference was insignificant. However, the population of beneficial bacteria, such as *Lactobacillus*, in the intestines of rats consuming MA flour was significantly higher when compared with rats consuming a standard diet (Harmayani *et al.*, 2011). This was because a large number of probiotics such as *L. casei* (strains rhamnosus and shirota) *Lactobacillus* G3, G1, and F1, *Bifidobacterium bifidum*, and *Bifidobacterium longum* can use the sugar extracted from MA flour to support their growth. The increasing growth of *Lactobacillus* G3 and *B. bifidum* enabled these probiotics to fight pathogenic bacteria such as *Salmonella*, *B. cereus*, and *E. coli*, thus leading to a decrease in pathogenic bacterial populations (Krisnayudha, 2007). In contrast, when the administration of MA tuber extract to rats was stopped, the amounts of *E. coli* increased while lactic acid bacteria decreased (Dwiari, 2008). Yogurt added with MA extract could potentially be preserved for longer and with a higher population of *Lactobacillus* as compared to control (yogurt without MA) (Abesinghe *et al.*, 2012). Yogurt with the addition of MA flour or starch (as much as 2.5 and 5%, respectively) showed a higher ability to inhibit bacteria as compared to the control, albeit indicating an insignificant difference (Rosa, 2010).

Maranta arundinacea has potential as a prebiotic since the sugar extracted from MA tuber flour contains raffinose and oligofructose (Krisnayudha, 2007). Several studies found that indigestible oligosaccharides were prebiotics that could increase normal microflora in the gastrointestinal tracts. This can lead to oligosaccharide fermentation by microflora which increases short-chain fatty acids (SCFAs), decreases intraluminal pH, and inhibits an increase in intestinal permeability, consequently preventing pathogenic bacteria from passing through the intestinal epithelial barrier (Slavin, 2013). *Staphylococcus epidermidis* causes nosocomial infections in immunocompromised patients. Herbal medicine consisting of MA (rhizome), *Oroxylum indicum* Vent. (bark), and *Commelina benghalensis* L. (the entire plant) can inhibit biofilm formation in *S. epidermidis* (Chusri *et al.*, 2012).

Immunomodulatory property

The MA flour extract in rat splenocyte cells could stimulate and increase the production of immunoglobulin (IgM), immunoglobulin G (IgG), and immunoglobulin A (IgA), as well as interferon gamma (INF-γ) *in vitro*, when compared with the control water. Likewise, the concentrations of IgG, IgM, and IgA *in vivo* in rat serum with an MA flour diet for 14 days were higher when compared with rats receiving the standard AIN-93M diet (Kumalasari *et al.*, 2012). However, other studies found no differences in IgA concentration in the faeces of children given MA cookies as a snack (Nurliyani *et al.*, 2013). The immunomodulatory ability of MA comes from its phenolic and flavonoid contents with antioxidant activities. Antioxidants such as vitamins C and E can improve the immune system, and are recommended as supportive therapy for chronic illness such as cancers. In addition, the carbohydrate, protein, mineral, and vitamin contents of MA tubers can also support metabolism and improve the immune system (Karacabey and Odzemir, 2012).

The ability of MA as prebiotic increases the fermentation of short SCFAs. These SCFAs can function as a source of energy for immune cells, and regulate differentiation, recruitment, and the activation of immune cells such as neutrophils, dendritic cells, macrophages, and T lymphocytes (Corrêa-Oliveira *et al.*, 2016). Furthermore, MA also has resistant starches, which in a previous study was administered to rats for four weeks, resulting in increased immunoglobulin A serum, and a higher population of CD4T cells in mesenteric lymph nodes (Song *et al.*, 2010).

Anti-ulcerative property

The administration of 4 g of MA tuber starch, three times a day, for 30 days, alongside regulated food intake such as no fried or spicy foods, and avoiding stress and too-little sleep could reduce 100% of the symptoms in one patient, and more than 75% of symptoms in 26/33 patients (81.82%) with amlapitta, a psychosomatic disease with non-ulcer gastritis hyperacidity (Rajashekhara and Sharma, 2010). The same study also found that patients experienced significant weight gain (on average 0.87%). Rats with ulceration due to pylorus ligation had a 56.81% decrease in gastric juice, 48.44% decrease in gastric acidity, 27.14% increase in gastric pH, 45.53% decrease in peptic activity, 56.44% increase in total carbohydrates, and nearly-normal gastric mucosa histology when administered with 1,100 mg/kg BW of MA starch in water for seven days before pylorus ligation. These findings indicated the ability of MA starch to prevent gastric ulceration, while data including body weight, total protein, and ulcer index were insignificantly different as compared to control (Rajashekhara *et al.*, 2014).

Gastric ulceration occurs because of an imbalance between mucosal defence and gastric acid production, thus leading to mucosal damage. The anti-ulcerative effect of MA is likely caused by its resistant starch content as shown in existing studies related to the anti-ulcerative mechanism of resistant starch, in which the starch increased the thickness of gastric mucosa and inhibited pro-inflammatory cytokines such as IL-6, IL-12, tumour necrosis factor-α, and IFN-γ (Qian *et al.*, 2013). Resistant starch also indirectly increases the number of normal bacterial flora in the intestine or probiotics. Meanwhile, probiotic bacteria can inhibit the development of *Helicobacter pylori*, and reduce the incidence of gastritis (Bird *et al.*, 2000).

Anti-diarrhoeal property

Food solutions derived from MA reduced diarrhoea in cholera toxin-induced model rats (Rolston *et al.*, 1990). In 11 human patients with irritable bowel syndrome, administration of 5 mL MA tuber powder three times reduced the incidence of diarrhoea, abdominal pain, and constipation, although one patient experienced worsening dyspepsia, one person had severe constipation, and two patients had moderate constipation (Cooke *et al.*, 2000). Diarrhoea can frequently lead to dehydration risk, thus making supportive therapy essential for oral rehydration solutions. Oral rehydration has long relied on pure glucose, which can prevent dehydration but raise osmolality, thus increasing the volume of faecal removal (Qi and Tester, 2018). Meanwhile, the glucose of resistant starch such as that derived from MA has lower molality, thus causing sodium absorption followed by water, resulting in a smaller volume of faeces. According to Kumalasari *et al.* (2012), the consumption of MA can improve the production of SCFAs which will be absorbed by the intestine, and can stimulate the absorption of electrolytes such as sodium, and assist in the absorption of liquids (Binder, 2010).

The MA plant also has the potential to prevent diarrhoea because consuming its tuber can increase the number of probiotic bacteria in the gastrointestinal tract which will have a positive impact on the health of gastrointestinal epithelial cells (Harmayani *et al.*, 2011). The starch of MA also includes 3 mg of zinc per 100 g (Madineni *et al.*, 2012); zinc consumption correlates with a healthy gastrointestinal tract. Children with diarrhoea are recommended to consume zinc to reduce the symptoms (Galvao *et al.*, 2013).

Hypoglycaemic property

An MA tuber infusion as high as 120 mg/kg BW administered for 28 days to streptozotocin-induced diabetic rat models showed significantly lower blood glucose levels, and significantly higher insulin levels as compared to rats without the infusion; the diabetic rat models also showed no differences when compared with healthy control rats (Yuniastuti *et al.*, 2018). The consumption of analogue rice from MA by mice for 20 weeks after receiving alloxan monohydrate showed a decrease in glucose levels by 18.97%. Conversely, giving IR64 rice increased glucose levels by 39.18% (Pricilla and Buana, 2020). The MA tuber is recommended for DM patients because of its low glycaemic index, reaching 14 according to Marsono (2002), and 32 according to Utami (2008). Glycaemic index is considered low when it is less than 55. Foods with a low glycaemic index indicate a low level of glucose absorption, thus reducing blood glucose levels. The MA plant has resistant starch with a chemical structure containing amylose which induces slow digestion (longer than 120 min) and is resistant to gastric enzymes (Yang *et al.*, 2017). Flour with high resistant starch can lower leptin blood concentration (Maziarz *et al.*, 2017), where low leptin concentration is associated with increased insulin sensitivity (Paz-Filho *et al.*, 2012). However, research involving 14 patients with T2DM who consumed 20 mg of crispy MA flakes per day as a snack for 30 days indicated no decrease in blood glucose levels (Prastuti and Sunarti, 2012).

These characteristics have encouraged nutritionists to add MA tuber as an additional ingredient in food production or to produce modified foods for DM patients. Snack bars containing 15% MA flour, 15% foxtail millet (*Setaria italica*), 30% red kidney beans, 18% margarine, 10% maltitol, and 12% egg yolk are recommended for DM patients due to their low glycaemic index of 36.7 (Lestari *et al.*, 2017). Fresh noodles mixed with MA flour are recommended over pure wheat noodles because of the former's low glycaemic index (Wijayanti *et al.*, 2014). Biscuits made from MA flour also had a lower glycaemic index as compared to wheat-flour biscuits (Gustiar, 2009). In addition, a snack bar composed of 70% arrowroot and 30% red bean has a low glycaemic index of only 25 (Indrastati and Anjani, 2016). Biscuits made from 20% *pedada* flour and 80% MA tuber had a lower glycaemic index and glycaemic load than sweet potato, potato, and cassava starch (Jariyah *et al.*, 2018).

Conversely, other studies reported no decrease in fasting blood glucose levels or glycated haemoglobin in DM patients who consumed a snack rich in fibre made from MA, *Dioscorea esculenta*, cassava, and pumpkin (as much as 32 g per day for four weeks) alongside a restricted diet of 1,500 kcal daily (Sunarti *et al.*, 2018). This had likely been due to other foods that were not reported, and limited only for the sake of calorie intake.

Hypocholesterolaemic property

Rats fed a cake made from 100% butyrylated MA starch for 28 days showed a significant decrease in total cholesterol, low-density lipoprotein (LDL) cholesterol, and triglyceride levels, as well as an increase in high-density lipoprotein (HDL) cholesterol levels, when compared with an AIN-93 standard rat diet with a cake made from 100% wheat flour (Damat, 2012). In 14 human patients with T2DM who consumed 20 mg MA crispy flakes daily as a snack, combined with a 1,500 kcal daily diet for one month, a significant weight loss and BMI reduction were observed as compared to a previous diet without crispy flakes. There was also an insignificant decrease in total cholesterol; instead, the triglyceride level significantly increased (Prastuti and Sunarti, 2012). Another study of 30 T2DM patients who consumed 21 g of MA crispy flakes per day for eight weeks also observed a weight loss, a decrease in waistline, and an increase in free fatty acids, although this was insignificant (Sunarti *et al.*, 2014). A snack made of mixed MA and *Dioscorea esculenta* given to T2DM patients also reduced non-HDL cholesterol levels and the atherogenic index (Sunarti *et al.*, 2018).

The MA tuber can reduce cholesterol levels because it contains soluble fibre which can bind to bile acid. Bile-acid binding can prevent re-absorption of acid or bile salt into the enterohepatic circulation; this causes a large amount of bile acid to be excreted through faeces, thereby reducing the cholesterol entering the body. The consumption of fibre can also inhibit glucose absorption, thus leading to decreased insulin levels. Decreased insulin levels will inhibit the 3-hydroxy-3-methylglutaryl coenzyme A reductase enzyme to synthesise cholesterol. Undigested soluble fibre will enter the colon, where it will be fermented by bacteria to form SCFAs such as acetate, propionate, and butyrate. Propionate and acetate will be absorbed and enter the hepatic portal vein, thus inhibiting the cholesterol synthesis by hepatic cells (Gunness and Gidley, 2010). In addition, the phytochemical content in MA such as flavonoids has antioxidant properties, and can inhibit xanthine oxidase enzymes, thus slowing down LDL oxidation and preventing atherosclerosis (Panche *et al.*, 2016).

Antihypertensive property

The potential of MA for weight loss enables a reduction in the number of adipocytes that can release angiotensinogen. Meanwhile, angiotensinogen can activate angiotensin I, which in combination with angiotensin-converting enzyme (ACE), will form angiotensin II. Angiotensin II can induce arterial vasoconstriction, thus leading to increased blood pressure (Fidianingsih, 2007). A study of T2DM patients consuming MA crispy flakes as a snack found a decrease, though not significant, in angiotensin II level, as well as in systolic and diastolic blood pressures (Novitasari *et al.*, 2011).

In several Asian countries, rice is a staple food source. Research on hypertensive rats fed with artificial rice made from MA tuber for four weeks showed that their systolic blood pressure decreased to normal as compared to rats given IR36 rice. That study also indicated that, as compared to IR36 rice, the artificial rice included more phenols, which inhibited the formation of endothelial nitric oxide synthase, thereby increasing NO. Nitric oxide can serve as a vasodilator for reducing blood pressure (Estiasih *et al.*, 2016).

Discussion

The MA plant has phytochemical components and antioxidant, anti-inflammatory, immunomodulatory, prebiotic, antibacterial, hypoglycaemic, hypocholesterolaemic, and antihypertensive properties. However, the results of current research in this area are limited to *in vitro* and animal studies. Its effect on humans has not yet been proven. We discovered several studies on the consumption of MA in humans; however, these were conducted in combination with other food ingredients. These articles were not included in the present review because the results were biased (Figure 1). The mechanisms underlying the ability of MA to affect health have also not been studied. These mechanisms are still limited to the assumption that MA contains phytochemical components such as phenols, saponins, and flavanones, in addition to having high fibre content. Functional food also requires proof related to bioavailability in the body, such as its absorption or bio-accessibility, distribution in tissue, and bioactivity (Motilva *et al.*, 2015). The results of this scoping review did not find MA research related to these matters.

Animal studies using MA extracts were primarily found. People tend to consume food that has been processed or cooked. Previous studies have shown that phenol levels can decrease following the cooking process and that antioxidant activity can also decrease after heating or extrusion (Yu *et al.*, 2013; Nindita *et al.*, 2018). Additional research on how much (doses) MA should be consumed after cooking for it to have positive health effects is still needed. Different types of MA processing will have different health effects. Fresh MA includes more components such as proteins, vitamins, and minerals (Table 2). Meanwhile, mineral and vitamin intakes are associated with an increase in antioxidants and a decrease in free radicals, which allows disease prevention (Kang *et al.*, 2019). Moreover, the modification of MA flour by acid hydrolysis and autoclaving-cooling cycling increases the resistant starch content (Faridah *et al.*, 2013). This starch is difficult to absorb and will undergo fermentation in the colon, thus increasing SCFAs. The consumption of resistant starch has been linked to decreased body fat and anti-obesity. Other benefits of consuming resistant starch include preventing gallstones, losing weight, and increasing the absorption of minerals including calcium, magnesium, zinc, iron, and copper (Yang *et al.*, 2017).

Indonesia has a high dependence on white rice as a staple food. White rice has a high glycaemic index, and as such, high consumption of white rice increases the risk of diabetes. The high carbohydrate content of MA alongside a low glycaemic index has the potential for being developed into artificial rice. However, the existing research in this regard is still in the trial stage for obtaining a suitable composition with the addition of other foods. Those studies only tested good physical, chemical, nutritional, and sensory properties, but did not observe the impacts on health (Wahjuningsih and Susanti, 2018; Rohmah, 2019; Damat *et al.*, 2019; 2020; Nugraheni *et al.*, 2020). In the present review, we found three *in vivo* studies of MA analogue rice involving experimental animals and assessment on health effects, but one study was excluded because other food was also assessed (Table 1). Further research on the potential health benefits of MA should be conducted including aspects such as good dosage amount and the effect of MA on disease prevention in humans.

Conclusion

In vitro and animal studies showed that MA tuber and rhizome has antioxidant, anti-inflammatory, immunomodulatory, prebiotic, antibacterial, hypoglycaemic, hypocholesterolaemic, and antihypertensive properties. However, its effects in terms of human use remain unknown. The claim of MA as a functional food thus requires further investigation.

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