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1	Jackfruit (Artocarpus heterophyllus) and Breadfruit (A. altilis): Phytochemistry, Pharmacology,					
2	Commercial Uses and Perspectives for Human Nourishment					
3						
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11						
12	Abstract					
13	The Artocarpus J. R. & G. Forster genus is comprised of about 50 species. Artocarpus is derived from the Greek					
14	word artos, meaning bread while karpos means fruit. There are two species that are widely distributed in tropical					
15	regions, Artocarpus heterophyllus Lam., known as jackfruit, and Artocarpus altilis (Parkinson) Fosberg, known					
16	as breadfruit, both in the Moraceae, or mulberry family. Both of these Artocarpus species have medicinal					
17	properties and biological activities that are derived from almost every part of the tree, from fruit, seed, wood,					
18	bark, leaves and sap. This review examines the limited work that has been conducted on the biology and					
19	biotechnology of these two Artocarpus species with the hope that this knowledge may spur further basic and					
20	applied research.					
21						
22	Keywords: fruit; medicine; Moraceae; secondary metabolites; tropical tree					
23						
24	Introduction					
25	The genus Artocarpus (Moraceae), which contains food-producing plants that are spread throughout tropical and					
26	subtropical regions of the world, consists of about 50 species (Motley, 2014), but The Plant List (2017) lists 167					
27	accepted names for Artocarpus, although many of them are synonymous and unresolved species. The word					

Artocarpus is a compilation of two Greek words, *artos*, which means bread, and *karpos*, which means fruit
(Jones et al., 2011).

30

31 The species epithet of jackfruit, *heterophyllus*, is a compilation of two Greek words, *hetero*, meaning different, 32 and *phyllus*, which means leaf (Gupta, 2011). This implies existing variation in the shape and size of the leaves. 33 Jackfruit, which typically grows in the form of a tree, provides edible fruit and medically potential secondary metabolites, is a source of timber, and has been cultivated throughout China, Sri Lanka, India, and Southeast 34 35 Asia, but is also found in Africa, the Caribbean islands, Brazil, Suriname, and tropical parts of Australia 36 (Thaman & Ali, 1993). Jackfruit is known as *nangka* in Indonesia and has various ethnobotanical properties that 37 derive from its ripe fruit which serve as ingredients for local sweets such as *kolak* and *dodol* in Java, young fruit is consumed as a vegetable, and its leaves are used as cattle feed (Lim, 2012). Ash of leaves can be used to treat 38 39 wounds and serve as medication to treat ulcers (Gogte, 2000). Jackfruit timber is a good wood for furniture, 40 construction material, and musical instruments since it resists bacterial, fungal, and termite attack (Orwa et al., 2009). 41

42

43 The methanolic extract of stem, root bark and heartwood, leaves, fruit, and seed have multiple antibacterial 44 compounds (Khan et al., 2003). One of those compounds, artocarpin, is used as an antitermite agent (Shibutani et al., 2006). The basal part of the fruit, which is fleshy, fibrous, and rich in sugar, provides a good natural source 45 46 of carbohydrates and minerals such as calcium, iron, magnesium, carboxylic acids, and vitamins A, C and E, 47 primarily ascorbic acid and thiamine (Rahman et al., 1999). Mature seed are edible when dried or after cooking by boiling and roasting. Fresh mature seed contain 25 IU/100 g of vitamin A, 4.3-6.6 g/100 g of protein, 23-25 48 g/100 g of calcium, 80-126 mg/100 g of phosphorus, and 10-17 mg/100 g of ascorbic acid (Acedo, 1992). In 49 50 fresh (raw) fruit, there are 23.25 g/100 g of carbohydrate, 24 mg/100 g of calcium, 0.23 mg/100 g of iron, 29 51 mg/100 g of magnesium, 110 IU/100 g of vitamin A, 13.7 mg/100 g of vitamin C (ascorbic acid), and 0.34 52 mg/100 g of vitamin E (α -tocopherol) (USDA, 2016). The latex, which also has anti-syphilitic and vermifuge properties, contains 71.8% resin, 63.3% of which are yellow fluavilles and 8.5% white albanes that are useful for 53 varnishes (Rao et al., 2014). A study conducted in New Delhi and Kerala, India by Suba Rao (1983) showed that 54

jackfruit is symbiotically asociated with Azotobacter and Beijerinckia, 35 and 4×10^4 /g soil, respectively at pH 55 6.8-7.5, and 14 and 18×10^4 /g soil, respectively at pH 3.5-5.5. According to Prakash et al. (2009), a hot water 56 extract of jackfruit leaves, when consumed orally by humans at 20 g/kg of the patient's weight, improves 57 58 glucose tolerance for mature-onset diabetic patients, while the crude methanolic extract of jackfruit parts (stem, 59 root heartwood, bark, leaves, fruits, and seeds) and their subsequent partitioning with petrol, dichloromethane, ethyl acetate, and butanol gave fractions that exhibited broad spectrum antibacterial activity, the most active 60 fraction being the butanolic extract of fruits and root bark. An extract from jackfruit shoots also revealed 61 62 nematicidal activity against Rotylenchulus reniformis, Tylenchorynchus brassicae, Tylenchus filiformis, and Meloidogyne incognita (Sharma & Trivedi, 1995 cit. Prakash et al., 2009). 63

64

The species epithet of A. altilis, the word altilis itself is a Greek word that means fat, refers to the fruit shape 65 66 (Small, 2011). Breadfruit, also a source of food, was first cultivated in the Western Pacific about 3000 years ago 67 and is native to the eastern part of Indonesia, New Guinea, Malaysia, and the Philippines (Orwa et al., 2009). The migration of Polynesians to South and South America, Africa (Senegal, Ghana, and Liberia), India, 68 69 Maldives, and Sri Lanka contributed to the distribution of breadfruit (Deivanai & Bhore, 2010). The breadfruit 70 tree is often employed in a mixed cropping system with yams, banana, black pepper, and coffee, although details 71 of these cropping systems are lacking (Ragone, 1997). The fruit of ripe breadfruit can be eaten fresh or cooked by steaming, roasting, and frying (Ragone, 1997). Leaves and the non-edible part of fruit can be used as cattle 72 feed while tree bark can also serve as feed for horses (Morton, 1987). In Samoa and several Pacific Islands, bark 73 74 is used to cure headaches, in Java and Malaya the toasted flower is used to treat toothache, while in the Bahamas, 75 leaves of A. altilis are used to relieve headaches (Kuete et al., 2011). In Indonesia, the methanolic or 76 dichloromethane extracts of leaves have medicinal properties and are used to cure liver cirrhosis, hypertension, 77 and diabetes (Kasahara & Hemmi, 1988; Arung et al., 2009). Similar to jackfruit, breadfruit trunk wood is good 78 for construction and furniture, and its sap can be used to trap birds and houseflies or to treat human skin and 79 fungal diseases (Ragone, 1997).

80

81 Jackfruit and breadfruit are tropical fruits with potential beneficial uses as food, timber, and ethnomedicines, but

that require scientific testing. This paper, in a bid to expand research of these trees, and expand their sustainable
use and production through biotechnological interventions, highlights their basic biology such as morphology,
medicinal properties, and propagation (both in classical and biotechnological approaches). In this paper, we
highlight research that has been conducted on two species, *A. heterophyllus* Lam. (syn: *A. integrifolia* Linn.) or
jackfruit, and *A. altilis* (Parkinson) Fosberg (syn: *A. communis* J.R. Forst & G. Forst; *A. incisus* (Thunb.) L.f.), or
breadfruit.

88

89 Morphology

Jackfruit is an evergreen tree 8-25 m in height and with a trunk diameter of 30-80 cm that can live up to a 100 years old. Young trees grow with a conical or pyramidal canopy shape that turns into a dome-shaped canopy as the plant grows older. Canopy diameter, which can reach 10 m, is close to the ground and provides dense shade (Elevitch & Manner, 2006). Wood of jackfruit is categorized as medium hardwood with a specific gravity of 0.6-0.7 (Orwa et al., 2009). When the tree ages, wood turns from yellow to red or brown. Breadfruit is also an evergreen tree 15-20 m in height and with a 1-2 m diameter trunk whose bark is smooth, thick and light-grey while wood is golden although, after exposure to air, it darkens (Ragone, 1997).

97

98 Jackfruit inflorescences sprout from a short, thick stalk and emerge from the lateral side of the main stem and thick branches (Backer & Bakhuizen, 1965). The male inflorescence forms in the axil of the apical branch with a 99 100 cylindrical to conic-ellipsoid shape 2-7 cm in diameter and a 1-5 cm long peduncle with a tubular calyx that has 101 a two-lobed apex 1-1.5 mm in diameter, pubescent texture, straight filament, and ellipsoid anther while the 102 female inflorescence has a globose fleshy rachis with a tubular calyx, lobed apex and a one-celled ovary (Zhou 103 & Gabriel, 2006). Some parts of the male inflorescence are sterile. As in jackfruit, the breadfruit inflorescence 104 emerges from the apical trunk (Fig. 1). The breadfruit inflorescence has a cylindric-clavate shaped flower with a 105 3-6 cm long peduncle, and globose or ellipsoid inflorescence shape with a diameter up to 20-30 cm. It has a 106 tubular calvx that is pubescent, has two lobes on its apical surface and has a lanceolate-shaped lobe while the 107 anthers are elliptic. Female breadfruit flowers have a tubular calyx, an ovoid ovary with a long style, and two branches on the apex. Each flower consists of a reduced tubular perianth that covers a single stamen with a two-108

lobed anther on a thick filament (Sharma, 1962).

110

Both jackfruit and breadfruit exude a sticky white latex from the injured parts of the plant (Rahman & Khanom, 111 112 2013), and forms part of the plants' defense against herbivory (Agrawal & Konno, 2009). The phyllotaxis (i.e., 113 leaf arrangement) of jackfruit and breadfruit is distichous or spiral with simple, leathery leaf blades with a full 114 margin, and plants are monoecious (i.e., male and female flowers on the same tree) with inflorescences growing from the main branch or trunk (cauliflory) for jackfruit but sprouting from the apex of the main branch, also 115 116 where new leaves emerge, and arising from simple, pseudomonomerous ovaries as in other Moraceae species 117 (Singh, 2016). Both jackfruit and breadfruit form a single leaf blade that is lobed, but mature jackfruit leaves become entire and lose their lobes, hence the species epithet, heterophyllus. The leaves of jackfruit and 118 119 breadfruit have stipulate leaf types, with an ovate form for jackfruit and a lanceolate to broadly lanceolate form 120 for breadfruit. Jackfruit leaves are spirally arranged with an elliptic to obovate leaf blade, leathery, leaf margins 121 are lobed in seedlings but entire in mature trees, with pale green on the lower leaf surfaces displaying scattered 122 globose to ellipsoid resin cells while the axial surface is dark green, smooth, and glossy (Zhou & Gilbert, 2003) 123 with a cuneate, subdecurrent base, firmly coriaceous, leaf size is $10-20 \times 5-10$ cm ($1 \times b$), the stipule is 1.5-5 cm, 124 and the petiole is 2-4 cm long (Backer & Bakhuizen, 1965). Breadfruit leaves are also spirally arranged, elliptic 125 in shape with a broadly cuneate or obtuse base, up to 3-7 lobed along each margin, lobes are oblong, longacuminate – acute, the stipule is 16-20 cm long, the petiole is 2-4 cm ling, and leaves are 30-100 cm \times 25-65 cm 126 (Backer & Bakhuizen, 1965). 127

128

Jackfruit and breadfruit have a compound fruit or syncarp that is classified as a compound false fruit or pseudofruit that forms from the enlargement of the stigma, and the inflorescence is composed of 1500-2000 flowers attached to the fruit's axis (Jarret, 1976). The fruit of jackfruit can weigh 4.5-30 Kg and can reach 30-40 cm in length, with an oblong-cylindrical shape and dark green coloration when young that turns greenish-yellow or brownish when mature. The fruit grows and matures on the trunk for 90-180 days (Elevitch & Manner, 2006). Some jackfruit achenes contain multiple fruits, each with a bulk composed of seed, and with a waxy and soft texture, golden-yellow with a sweet and aromatic aril (Orwa et al., 2009). The fruit of breadfruit is formed from the fused flower perianth, except for the base (Reeve, 1974), young fruit is light-green but turns yellowish-green
when mature, and as the fruit develops, perianths fuse, becoming the fleshy edible portion of the fruit (Ragone,
1977). When sliced, breadfruit has a white flesh composed of dense perianths (Fig. 2).

139

140 Jackfruit seed are semi-round, light brown to brown, 2-3 cm in length and 1-1.5 cm in diameter, wrapped in a whitish seed coat/testa, and a vellow aril (Fig. 3). The seed is recalcitrant and can be stored for up to a month in 141 humid conditions (Elevitch & Manner, 2006). Adelina et al. (2014) air-dried seeds for 0 h (control) to 5 h 142 143 (treatments separated by 1 h) at 28°C and 70% humidity, noticing that water content was reduced from 75.03% 144 to 22.95%, seed respiration rate declined from 7.189 mg CO₂/kg h to 5.32 mg CO₂/kg h, and seed viability dropped after 14 days of germination from 97.33% to 24.67%. The seed of breadfruit is brown, round or obovoid 145 146 in shape with a thin wall 1-2 cm thick with reduced or no endosperm, hence its recalcitrance to storage or 147 desiccation (Ragone, 1997). Some modern bread breadfruit cultivars are seedless (Devanai & Bhore, 2010). The 148 male inflorescence of seedless cultivars produces less viable pollen than fertile, less-seeded cultivars and only 149 few flowers in the male inflorescence produce and release pollen (Devanai & Bhore, 2010). In seedless 150 breadfruit cultivars, nectar is only produced in male flowers but not in female flowers (Ragone, 1997). In 151 general, the loss of fertility in breadfruit is caused by triploidy (2n = 3x = -84) or by sterile diploids (2n = 2x = -84)152 56) that result from hybridization (Ragone, 2001).

153

154 Medicinal properties

155 Artocarpus produces various secondary metabolites and biologically active compounds, particularly phenolic 156 compounds such as flavonoids (Table 1), stilbenoids, and arylbenzofurans (Hakim et al., 2006), extracted from 157 leaves, the stem, fruit, and bark, which have ethnomedicinal uses and antibacterial (Khan et al., 2003), antiviral (Likhitwitayawuid et al., 2005; 2006), antifungal towards Herpes Simplex Virus (HSV) and Human 158 159 Immunodeficiency Virus (HIV) (Javasinghe et al., 2004; Trindade et al., 2006), antiplatelet (inhibitory of 160 thromboxane formation) (Weng et al., 2006), antiarthritic (Ngoc et al., 2005), tryrosinase inhibitory (Arung et 161 al., 2006; Likhitwitayawuid & Sritularak, 2001) and cytotoxicity properties (Hakim et al., 2006) (reviewed in greater detail by Jagtap & Bapat, 2010). Jacalin, which is a tetrameric two-chain lectin extracted from A. 162

heterophyllus, has strong mitogenic activity against human CD4⁺ T lymphocytes, serving as an
 immunobiological diagnosis agent for HIV-1 patients (Kabir, 1998).

165

166 Jackfruit, which contains various components used for medical benefits. Some flavonoids (Table 2) are used as 167 antinflammatory agents (Wei et al., 2005). Fang et al. (2008) extracted three phenolic compounds from the ethyl 168 acetate fraction of jackfruit fruit: artocarpesin $(5,7,2',4'-\text{tetrahydroxy}-6-\beta-\text{methylbut}-3-\text{enyl flavone})$, 169 norartocarpetin (5,7,2'4'-tetrahydroxyflavone), and oxyresveratrol (trans-2,4,3',5'tetrahydroxystilbene). All 170 three compounds showed a potent anti-inflammatory property after inhibiting lipopolysaccharide-activated RAW 171 264.7 murine macrophage cells. Other compounds, cycloheterophyllin and artonins A and B, showed antioxidant 172 properties as they inhibited iron-induced lipid peroxidation after exposure to oxygen radicals in more than 60% 173 of a rat brain homogenate after the addition of 1 μ M of each of the three compounds and in more than 80% when 174 3 µM was used (Ko et al., 1998). A chitin-binding lectin, jackin, which was purified from a saline crude extract of jackfruit seed, displayed anti-fungal properties, inhibiting the growth of Fusarium moniliforme and 175 176 Aspergillus niger cultures (2.25 mg/ml, but no effect for A. niger at 4.5 mg/ml) and induced hemagglutination 177 against human and rabbit erythrocytes (with at least 0.15 mg/ml) (Trindade et al., 2006). Jacalin, a 65 kDA two-178 chain lectin, has potential as an immunomodulatory agent, having shown mitogenicity against human CD4⁺ T 179 lymphocytes when added at 100 µg/ml (Blasco et al., 1995). The addition of 10, 20, 30, and 40 µg/ml of jackfruit lectin displayed *in vitro* inhibitory activity against herpes simplex virus type HSV-2, varicellazoster virus (VSZ), 180 and cytomegalovirus (CMV) via a cytopathic effect, and inhibited HIV-1 infection in vitro by preventing the 181 182 binding of the virus to host cells (Wetprasit et al., 2000; Swami et al., 2012).

183

The methanolic and ethyl acetate extracts from breadfruit fruit contain steroids, phenolics, and flavonoids that can inhibit the growth of human pathogenic bacteria like *Enterococcus faecalis*, *Staphylococcus aureus*, *Streptococcus mutans*, and *Pseudomonas aeruginosa* by establishing a defense mechanism (Pradhan et al., 2013). During a test on mice, the methanolic extract of breadfruit fruit and leaves (500 µg/ml each) was used to treat inflammation by lowering the intensity of leukocyte infiltration by preventing skin tumor growth and angiogenesis induced by carcinogenic chemicals 30 min after treatment (Lin et al., 2014). Fruitackin, a lectin isolated from the saline crude extract of breadfruit seed, induced hemagglutination against human and rabbit erythrocytes when added at 0.15 mg/ml and exhibits antifungal activity against *Fusarium moniliforme* and *Aspergilus niger* at the same concentration as used for jackin (2.25 mg/ml, but no effect on *A. niger* at 4.5 mg/ml) (Trindade et al., 2006).

194

195 Propagation (classical and biotechnological)

Conventional vegetative propagation using cuttings, grafting, and rootstocks have unsuccessfully been used to
propagate *A. heterophyllus* and *A. altilis*, thus seed serve as an effective choice to propagate *A. heterophyllus*(Roy et al., 1993). *In vitro* culture is an effective solution to cultivate and mass-produce both species.

199

200 Roy et al. (1993) first washed adventitious shoot buds in 100 ml of 0.7% polyvinylpyrrolidone (PVP) with 2% 201 sucrose, shook them at 100 rpm for 3 min then washed buds with tap water to remove PVP. Buds were disinfected in 0.2% HgCl₂ for 5 min then rinsed with sterile double-distilled water (SDW) for 3 min, and this 202 procedure was repeated 3-5 times. Buds cultured on Difco bacto-agar-solidified Murashige & Skoog (1962) 203 204 (MS) basal medium supplemented with 8.88 μ M 6-benzyladenine (BA) and 2.68 μ M α -naphthaleneacetic acid (NAA) induced 10 shoots/explant after the 7th subculture. Shoots were elongated on MS medium with 4.44 µM 205 BA, 0.54 µM NAA and 10% (v/v) coconut milk. Shoots were rooted in vitro on half-strength MS medium with 206 5.37 µM NAA and 4.92 µM indole-3-butyric acid (IBA), 80% of shoots being able to root. Plantlets were 207 208 transplanted into earthen pots containing sterile sand, soil, and humus (1:2:1, v/v/v), and 75% survived after 30 209 days.

210

Amin & Jaiswal (1993) used 10-20 days' old terminal buds from an *A. heterophyllus* trunk from a 30-50 yearold tree grown from seeds. Stems were washed in running tap water, treated with 1% (v/v) Cevalon[®] (an antiseptic and detergent), disinfected in 0.1% HgCl₂ for 5 min, then rinsed with SDW 4-5 times. Explants (5-10 mm denuded buds) were prepared by removing the outer cover of green stipules and excising inner buds encased by creamy-white stipules before implanting them vertically on growth medium, and placing cultures at $26\pm1^{\circ}$ C, a 16-h photoperiod (50-70 µmol m⁻² s⁻¹), and subculturing them every 4-5 weeks. MS basal medium with four

concentrations (4.5, 9.0, 18.0, and 36.0 µM) of BA and kinetin (Kin) and a combination of BA and Kin (4.5 µM 217 each) were used to induce shoots while MS with two concentrations of BA (4.5 µM and 9.0 µM) and BA with 218 Kin (4.5 µM each) were used to multiply shoots. Roots were successfully induced from shoots with four 219 220 combinations (0.5, 5.0, 10.0, and 25.0 μ M) each of NAA and IBA, or two combinations (5.0 + 5.0 and 10.0 + 221 10.0 μ M of NAA and IBA). The highest percentage of bud break resulted from 9.0 μ M BA (82±6%) while BA + 222 Kin (4.5 μ M each) resulted in 90±7%. The highest number of shoots/explants formed with 4.5 μ M BA (3.5±0.6), 223 or 38±1.1 for BA + Kin (4.5 µM each). Under ex vitro conditions, the survival percentage of regenerated 224 plantlets was 50%.

225

226 A. altilis can be propagated vegetatively in vivo and in vitro. In vivo vegetative propagation can be achieved by 227 cuttings and air layering of branches by removing the ring bark, covering the wound with peat moss, and then 228 encapsulating in plastic to induce rooting before being cut and placed on soil (Deivanai & Bhore, 2010), although details about how long it takes to achieve each step was not explained. In vitro propagation of A. altilis 229 230 can be achieved using shoot tips (Rouse-Miller & Duncan, 2000; Murch et al., 2008). Rouse-Miller & Duncan (2000) collected shoot tips from a 6-7 year-old tree during the dry season (December to April in Trinidad-231 232 Tobago). Explants with one or two expanded leaves and 3-6 cm of associated stem were collected and placed in 233 water (period of time not specified). Expanded leaves and bracts surrounding the shoot tip were removed and shoots were rinsed in tap water before cleansing in 70% ethanol for 1 min. Shoots were reduced to 1 cm, dipped 234 235 in 70% ethanol for 30 s, 10% household bleach (5.25% available chlorine) for 10 min, and rinsed three times in 236 sterile distilled water. The Rouse-Miller & Duncan (2000) study used Margara (1978) nutrients (Table 3). For 237 shoot induction, N5K and N15K macronutrients (Margara, 1978), MS micronutrients and vitamins with 3% sucrose, 0.8% agar, and 4.4 µM BA were necessary. Shoot proliferation required Margara (1978) N30NH4 238 239 macronutrients, MS micronutrients, vitamins, 3% sucrose, and 2.2 µM zeatin. Rooting required N30NH₄ 240 macronutrients, vitamins, 2% sucrose, with 0.5, 1.0, 1.5, 2.0, and 2.5 µM IBA. However, IBA alone could not 241 induce roots, and 60% of shoots formed roots in auxin-free medium (N3ONH₄ in Table 3; Margara, 1978). Murch et al. (2008) used MS or B5 (Gamborg et al., 1968) media with 2.5 g/L gelrite and 3% sucrose, 2 µM BA 242 and 3 μ M Kin to induce shoots in A. *altilis* within one week, and 1 μ M IAA to induce roots. 243

245 Molecular advances and future perspectives

Molecular studies of both jackfruit and breadfruit offer promising prospects for exploiting biotechnology- and 246 247 industry-derived benefits. Breadfruit molecular genetics has been studied more than in jackfruit. Studies on the 248 genetic identification and profiling of breadfruit used microsatellite or short sequence repeats, identifying around 249 65 loci for nuclear genomic DNA (Witherup et al., 2013; De Bellis et al., 2016) or 15 loci for chloroplast 250 genomic DNA (Elliot et al., 2015). Multi-access identification key software to identify breadfruit cultivars has 251 been developed from a prototype version on a Lucid 3.3 platform based on quantitative and qualitative traits 252 (Jones et al., 2013). Amplified fragment length polymorphism (AFLP) has been used to identify and track the 253 origin of breadfruit cultivars as linked to the routes of human migration in Oceania (Zerega et al., 2004), or to 254 assess genetic diversity (Shyamalamma et al., 2008). Random amplified polymorphic DNA (RAPD) was also 255 used to assess genetic diversity (Prasad et al., 2014) and fruit cracking in jackfruit (Singh et al., 2011). 256 Chloroplast and nuclear DNA were used to assess the phylogeny of 60 Moraceae taxa, including the Artocarpus 257 genus (Zerega et al., 2010). Gibberellin 20-oxidase genes isolated from breadfruit allowed for the detection of 258 sequence variants, their role in stem elongation after cuttings were treated with paclobutrazol (a GA inhibitor), 259 and their regulation of abiotic stress, namely salinity and drought (Zhou & Underhill, 2015, 2016). Future 260 research needs to identify breadfruit and jackfruit genetic diversity more precisely while studies on molecular genetics related to metabolic biosynthetic pathways, for example the elucidation of genes coding for artocarpatin 261 262 synthesis, would allow for applications in the pharmaceutical industry.

263

Jackfruit and breadfruit are still known locally but may be good sources of nutrients ranging from carbohydrates to secondary metabolites. These fruits could be useful germplasm in future plant breeding projects for improving fruit, such as fortifying stress tolerance. Roy et al. (1993) bred flood-resistance jackfruit plants *in vitro* as a way to solve the problem of annual flooding in Bangladesh. A breeding program conducted in South Florida aimed to improve jackfruit aroma, edible percentage, flesh firmness, color, and flavor (Campbell et al., 2004). A redfleshed variant of jackfruit exists in India (International Tropical Fruits Network, 2011). These color variants can be used to attract more consumers and thus achieve the maximum benefits of jackfruit, thus breeding for more

colorful fruit flesh could be important. For the nutraceutical and pharmaceutical industries, future jackfruit 271 breeding for higher content of specific metabolites can be achieved in a similar way as "Gama Melon Parfum", a 272 melon cultivar that was developed in Indonesia to obtain a higher yield of sesquiterpenes aimed for perfume 273 274 production (Maryanto et al., 2014). Breadfruit coloration is mostly only white, but it has some shape variants 275 ranging from oval to long fruits (McCormack, 2007). As breadfruit appears to have potential as a better source of 276 starch used in drug tablets than cornstarch (Adebayo et al., 2006a breeding programme to produce a higher yield 277 of starch in breadfruit could be a good prospect. Similar prospects for jackfruit could also be applied to 278 breadfruit in future by creating colour variants for increased appeal or to improve metabolite content for the 279 food, pharmaceutical and nutraceutical industries. As one example, breadfruit flour was found to be a good 280 substitute for wheat flour when used as a composite breadfruit-wheat flour mix for donuts, with a larger ratio of 281 breadfruit flour resulting in lighter donuts, apparently as a result if its lower gluten content, although panelists 282 preferred the color, aroma, taste, and texture of donuts with more wheat flour in the dough (Oke et al., 2018). 283 284 **Authors' contributions** 285 All three authors contributed equally to the conception, development, writing and revisions of this paper. 286 287 **Conflicts of interest** All authors declare no conflicts of interest. 288 289 290 References 291 Adelina E, Sutopo L, Guritno B, Kuswanto. 2014. Mutual effect of drying on jackfruit (Artocarpus heterophyllus 292 Lamk.) seed viability to water critical level for storage indicator. Scholars Academic Journal of Biosciences 293 **2(12B):** 909-912. 294 Agrawal AA, Konno K. 2009. Latex: a model for understanding mechanisms, ecology, and evolution of plant 295 defense against herbivory. Annual Reviews of Ecology, Evolution, and Systematics 40: 311-331. Acedo AL. 1992. Multipurpose Tree Species Network Series: Jackfruit biology, production, use, and Philippine 296

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Compound class	Typical group found			
Flavonoids	Chalcone			
	Flavanone			
	Flavone			
	Flavan-3-ol			
	3-Prenylflavone			
Modified flavonoids	Oxipinoflavone			
	Pyranoflavone			
	Dihydrobenzoxanthone			
	Furanodihydrobenzoxanthone			
	Pyranodihydrobenzoxanthone			
Flavonoid-derived xanthones	Quinonoxanthone			
	Cyclopentenoxanthone			
	Xanthonolide			
	Dihydroxanthone			
	Cyclopentenochromone			

Table 1. Typical flavonoids, modified flavonoids, and flavonoid-derived xanthones found in Artocarpus (Hakim et al., 2006) 1

Cudraflavone A

Cyclocommunin

Artomunoxanthone

Cycloheterohyllin

Artonin A and B

Artocarpanone A

Heteroflavone A, B, and C

4 5

	Macronutrients (mg/L)							
Medium	KNO ₃	NaNO ₃	NH ₄ NO ₃	$Ca(NO_3)_2 \bullet 4H_2O$	CaCl ₂ •2H ₂ O	MgSO ₄ •7H ₂ O	KCl	KH ₂ PO ₄
N5Ca			80	354	292	246	149	136
N30Ca	808		480	1180		246	74.5	136
N30K	1313		480	590		246	74.5	136
N15K*	606		240	354		246	149	136
N15Ca	101		240	944		246	149	136
N45K	1818	85	720	944		246	372.5	136
N5K*	75.8		80	265.5		246	372.5	136
N3ONH ₄ *	606		800	472		246	372.5	136
				Micronut	rients (µg/L)			
Medium	MnCl ₂	ZnSO ₄ •H ₂ O	H ₃ BO ₃	KI	CuSO ₄ •5H ₂ O	NaMoO ₄ •H ₂ O	FeSO ₄ •7H ₂ O	NaEDTA•2H ₂ O
All	157	500	500	10	100	59	35000	30000

6 Table 3. Margara (1978) nutrient lists according to Karla da Silva (2010).

* only the macronutrients were used in the Rouse-Miller and Duncan (2000) study

1 Figure legends

- 3 Fig. 1. Jackfruit young fruit (left) and mature fruit (right). White scale bar = 10 cm. Unpublished figure.



Fig. 2. Breadfruit: whole (left) and sliced (right). Scale bar = 5 cm. Unpublished figure.



Fig. 3. Mature fruit of jackfruit (A), sliced (B), part of the fruit with arils and the seed covered with testa (C), and
jackfruit seeds with testa (left) and still wrapped with aril (right). Blue lines indicate the direction of cuts. Scale
bar = 5 cm. Unpublished figure.

