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THE POTENTIAL IMPACTS OF SYNTHETIC BIOLOGY ON LIVELIHOODS AND BIODIVERSITY: THE CASE OF COCONUT OIL, PALM KERNEL OIL AND BABASSU

PRODUCT: Industrially useful natural fatty acids known as 'lauric oils' – capric acid, lauric acid, myristic acid, palmitic acid – are currently derived from coconut oil, palm kernel oil and also babassu seed. So too are a suite of 'fatty alcohol' ingredients such as lauryl alcohol and myristyl alcohol. These are the key ingredients for common oleochemical products such as detergents, soaps and cosmetics.

STATUS: Three California-based companies are now producing fatty acids and fatty alcohols using synthetic biology. **Solazyme, Inc.** has engineered algae to create strains whose oils are 'genetically tailored' to express lauric acid, capric acid or myristic acid. Solazyme is also developing strains to produce palmitic acid and oleic acid.[1] **Codexis, Inc.** and **LS9, Inc**. have developed engineered microbes that produce fatty alcohols for detergents.[2]

AFFECTED COUNTRIES/REGIONS: 58% of global oleochemicals production is in Asia,[3] as is most production of coconut and palm kernel nuts. Babassu palm is grown in Brazil. Countries most affected will be the Philippines, Malaysia, Indonesia and India. Vietnam, Mexico, Nigeria, Thailand and Papua New Guinea also have sizable coconut and palm kernel production. In the Philippines, approximately one quarter of the population depends on coconut production – impacting around 25 million people.[4]

MARKET: The global market for natural fatty acids (primarily derived from coconut, palm and palm kernel oil) was valued at $7.2 billion in 2011 and is expected to reach $13 billion by 2017.[5] The market for lauric acid alone was estimated at about $1.4 billion in 2008;[6] the market for myristic acid is estimated at about $600 million.[7] In 2011, the market for palm kernel oil was estimated at $9.3 billion and coconut oil at $5.3 billion.[8] This is just part of a larger $206 billion plant oils market that new SynBio companies are hoping to capture.[9] Detergent alcohols in particular are a $6 billion market worldwide, expected to reach $8 billion in a decade.[10]

COMMERCIALIZATION: Solazyme already has a production facility in the USA and has partnered with a number of key players to begin commercialization of its lauric oils. These partners include chemical giant Mitsui, household products transnational Unilever, grain traders Archer Daniels Midland and Bunge, as well as chemical firm AkzoNobel. Solazyme may have the technical capacity to capture up to 40% of global myristic acid production in the coming years with a new 100,000 MT/annum (metric tonnes per year) plant under construction in Brazil in collaboration with Bunge. Codexis is already selling small quantities of its CodeXol fatty alcohols and is hoping to have a 60,000 MT/annum commercial production plant running by 2015. In 2012, LS9, Inc. produced 135,000 litres of synbiotech-derived fatty alcohols and is now scaling up to supply customers, including Procter & Gamble.

Background

Synthetic Biology

"Synthetic biologists" apply computer-aided design and engineering to living organisms. The aim is to redesign existing biological organisms and even to create entirely new ones. Synthetic biology is "extreme genetic engineering" and its goal is to derive commercially-valuable compounds from novel living organisms rather than from conventional sources (e.g., crops, petroleum).

Currently, synthetic biology companies are engineering 'metabolic pathways' in microbes in order to create 'biological factories' that produce desired compounds. According to current scientific understanding, as few as eight key metabolic pathways may be responsible for almost all of the 200,000 known natural plant compounds. Synthetic biologists are rapidly decoding, re-constructing and patenting these pathways. In the words of one synthetic biologist: "We ought to be able to make any compound produced by a plant inside a microbe."[11]

Initially, synthetic biology companies focused on biofuels, but due to problems with scale-up, some companies are shifting focus from biofuels to high-value / lower-volume products – especially compounds found in plants (e.g., essential oils, flavours, fragrances, colourants and pharmaceuticals) – which are traditionally cultivated by farming communities in the global South.

If commercially viable, synthetic biology's patented organisms have the potential to de-stabilize natural product markets, disrupt trade and eliminate jobs and livelihoods. New, bio-based substitutes deemed 'equivalent' to natural products could have far-reaching impacts on agricultural economies, especially for those producers without the information or resources to respond to sudden shifts in natural resource supply chains.

Natural oleochemicals

Oleochemicals are those chemical products produced from oils, a large part of whose market is for 'natural oleochemicals' that refine vegetable oils into detergents, soaps, shampoos and other household goods. An important range of starter compounds for oleochemicals is the natural fatty acids known as 'lauric oils.' For these, coconut oil and palm kernel oil (different from palm oil, which comes from the pulp of the palm fruit) are the major raw material sources – occasionally supplemented by small amounts of babassu oil, derived from the Brazilian babassu palm. Palm kernel oil is

Coconut oil, produced from crushing the copra (flesh of matured fruit) of harvested coconuts is particularly rich in lauric oils and supplies much of the oleochemical market. Coconut oil consists of about 48% lauric acid, 16% myristic acid and 9% palmitic acid.[12] It is also a good source of capric or caprylic acid. Coconut oil and palm kernel oil are also the major industrial sources for C12-C14 fatty alcohols (C12-C14 refers to the length of the chain of carbon molecules), such as lauryl alcohol and myristyl alcohol; these are used primarily for detergents. The largest users of coconut- and palm kernel-derived detergent alcohols are consumer products companies, including US-based Procter & Gamble, Netherlands-based Unilever and Germany-based Henkel.

COCONUT OIL PRODUCTION IN THE PHILIPPINES AND BEYOND

Known in the Philippines as 'The Tree of Life,' the coconut tree (*Cocos nucifera*) is celebrated for its many uses, from food and clothing to building materials. However, it is the copra crushed into oil that is primarily sold internationally as a commodity both for food and more commonly for detergents, soaps, etc. Global production of coconut oil is estimated at 3,735,000 MT for 2013[13] with over 90% of that grown in Asia and the South Pacific. On average, 1000 coconuts yield 110 kg of oil.[14]

The Philippines is the world's leading producer of coconuts accounting for 46.2% of global coconut oil production and 59% of the world's coconut exports.[15] There are around 3.5 million coconut farmers and as many as 25 million people are directly or indirectly dependent on the coconut industry (e.g., coconut growing, transport, processing and trading). Coconut farming is distributed across the entire country: of 79 provinces, 68 are coconut-growing areas and coconut is grown on 26% of Philippine farmland (~324 million trees[16]). The coconut farms of the Philippines are relatively small – with an average area of 2.4 hectares (ha) and about two-thirds of the country's 1.4 million coconut farms are owner-operated. Coconut cultivation in the Philippines generally does not require chemical inputs, and other crops are often grown together under the tall trees' shade. Despite their contribution to the country's annual GDP, poverty incidence among Filipino coconut farmers is about 62%, due to stagnation of copra prices since 2010 and low wages for workers. Other major coconut-producing countries include Indonesia (26.1% of world coconut oil production), India (12%) Vietnam (4.1%) and Mexico (3.9%).

Top 10 Coconut Oil Producing Countries / 2013 Estimate[17]

Country	Production 2013 (1000 MT)	Market Share (% of world production)
1. Philippines	1,725	46.2
2. Indonesia	974	26.1
3. India	447	12
4. Viet Nam	153	4.1
5. Mexico	145	3.9
6. Papua New Guinea	63	1.7
7. Thailand	46	1.2
8. Sri Lanka	43	1.1
9. Malaysia	35	0.9
10. Mozambique	30	0.8
Total top 10	***3,661***	***98%***

Estimated world coconut oil production for 2013: 3,735,000 MT

Palm kernel oil production

About 74% of the world's production of palm oil is used for food; the remaining 26% is used for industrial products.[18] When the fruit of oil palm trees is processed into palm oil, the seed is kept aside and crushed separately into 'palm kernel oil' (PKO); consequently the palm kernel oil market is closely tied to the palm oil market. PKO is high in lauric oils and is commonly used as an ingredient in processed foods due to its relatively low cost and ability to withstand high cooking temperatures. Currently 86% of the world's supply of palm oil[19] comes from large industrial plantations in Indonesia (7.65 million ha)[20] and Malaysia (4.917 million ha);[21] consequently, those two countries dominate palm kernel oil production. Smaller amounts are grown in Nigeria, Thailand, Colombia and Papua New Guinea.

Replacing palm kernel oil with synbiotech substitutes

The past ten years have seen a significant increase in palm oil plantings due to the growth in support for biofuels, through direct and indirect subsidies. This has raised much concern about the accompanying destruction of forests, particularly ape habitats, release of carbon from cleared peatland and the impact on migrant workers and forest communities. According to Friends of the Earth, some estimates show an area the size of Greece being cleared every year for palm oil plantations[22] and investigations by the CSO Grain uncovered land grabs (millions of hectares) for oil palm plantations across Asia, Africa and South America.[23] Because of the environmentally destructive profile of palm oil (including palm kernel oil), some of the corporate investments in producing lauric oils through synthetic biology have been promoted as environmentally beneficial. In 2010, Unilever, the world's largest user of palm oil, announced a multimillion dollar investment in Solazyme, signalling that the move was environmentally motivated: "To Wash Hands of Palm Oil Unilever Embraces Algae: Consumer-Goods Maker Invests in California's Solazyme to Avoid Environmental Concerns," announced the *Wall Street Journal*.[24] While moving away from destructive palm oil is to be welcomed, any supposed environmental gain needs to be weighed against these considerations:

1) Switching from palm kernel oil to synthetic biology-derived fatty acids doesn't directly slow the market for palm oil. Indeed, given the growing interest in palm oil for biofuels and the concentrated nature of the market, the price of palm kernel oil may prove quite elastic. If so, the coconut oil market may suffer more.
2) The environmental benefits of switching from monoculture palm may be offset by the increased use of agricultural sugars as feedstocks for the synthetic organisms producing the oil. Sugar production, like palm production, is associated with land clearance for intensive monocultures, large scale releases of greenhouse gases, significant agrochemical use and poor working conditions for sugar workers.[25] Sugarcane expansion in Brazil has been implicated in pushing the agricultural frontier deeper into the Amazon, begging the question of whether Unilever's investment in Solazyme ultimately implies only a change of scenery: forest destruction in Indonesia to forest destruction in Brazil.

Top 10 Palm Kernel Oil Producing Countries / 2013 estimate[26]

Country	**Production 2013 (1,000 MT)**	**Market Share (% of world production)**
1. Indonesia	3,588	52.8
2. Malaysia	2,180	32.1
3. Nigeria	305	4.4
4. Thailand	190	2.8
5. Columbia	100	1.4
6. Papua New Guinea	60	0.9
7. Ecuador	51	0.7
8. Brazil	43	0.6
9. Côte D'Ivoire	39	0.6
10. Cameroon	32	0.5
Total top 10	***6,588***	***96.8%***

Estimated world palm kernel oil production in 2013: 6,796,000 MT

BABASSU OIL PRODUCTION

Babassu oil is extracted from the kernels of the Babassu palm tree, which originates in the Amazon and is grown widely in the Brazilian states of Maranhão and Piauí.[27] The oil's properties are similar to coconut oil's; babassu oil contains 50% lauric acid and 20% myristic acid.[28] Babassu palm is an aggressive weedy species able to flourish in different ecosystems and can form forest-like expanses of millions of hectares that look like plantations but are in fact naturally seeded.

Removing Babassu kernels is labour-intensive, and is traditionally carried out by women known as 'Babassu crackers' who sell the kernels to traders who, in turn, sell to industrial oleochemical processors.[29] According to *Biofuels Digest*, more than 400,000 women and their families process the palm for oil, soaps, flour and animal feed.[30] Babassu oil is generally not traded internationally; most of the oil produced is reserved for Brazilian cosmetics.

CURRENT STATE OF SYNTHETIC BIOLOGY ALTERNATIVES TO FATTY ACIDS AND ALCOHOLS

SOLAZYME: MAKING FATTY ACITDS IN ALGAE

Solazyme, Inc. of California, USA is a publicly-traded synthetic biology company with a business plan to engineer algae in order to change the chemical profile of algal oil. Unlike most algae companies, Solazyme works with heterotrophic algae – strains that feed on sugar instead of sunlight and so can be grown in closed vats in an industrial facility rather than shallow ponds.[31] While Solazyme was initially founded as a biofuels business, like many synthetic biology companies, it has shifted its business plan to produce natural compounds, flavours and food ingredients. Solazyme has engineered its algae to produce a range of "genetically tailored oils," which each express high levels of a particular fatty acid. The company claims it has developed algal strains that express up to 80% of their oil as lauric oils (cf. palm kernel oil's 55% lauric oils and coconut oil's 68%). Solazyme claims that an oleochemical facility utilizing its tailored oil rather than standard palm kernel oil could increase output of the desired fatty acid components such as capric, lauric and myristic acid by more than 30%.[32]

In particular, Solazyme trumpets its ability to compete against natural coconut oil as a better source of myristic acid. According to Solazyme, coconut oil can sometimes reach concentrations of up to 15% myristic acid. By contrast, Solazyme's engineered algal oil currently boasts 60% concentration of myristic acid, almost four times more than any widely available oil today.[33] As market analyst Kevin Quon points out:

> "This results in more than a 150% increase over that which is found in coconut oil. Through rough calculations, it would appear that in order to get 1 MT of myristic acid, it would either take 2.5 MT of tailored algal oil yielding 40% or it would take 6.67 MT of coconut oil yielding

> 15%. If we were looking just for myristic acid, it would therefore take 63% less oil in order to get it from Solazyme's tailored algal oil."[34]

Solazyme says their lauric oils will become commercially available toward the end of 2013.

How Solazyme's algal myristic acid will fare against coconut-derived myristic acid in the marketplace depends in part on coconut oil prices and sugarcane prices (sugar is the feedstock for the company's engineered algae). Solazyme is keen to point out that while most coconut is sourced from the Philippines and takes several years to grow, sugarcane can be grown quickly in many locations, including in coconut-producing countries such as the Philippines. In time, Solazyme hopes to feed cheaper cellulosic sugars to their algae (e.g., grasses or wood pulp): "…oil supply can be unlocked from a regional land restriction. Instead, the range is increased to include anywhere in which more-readily abundant sugarcane is grown. Once the ideal infrastructure is developed, it can even be produced at any location where cellulosic biomass is found."[35]

Solazyme has told investors that it would be able to manufacture oils at a cost below $1000 per MT if produced in a built-for-purpose commercial plant,[36] although they currently plan to sell their myristic acid for around $3000/MT.[37] Today, myristic acid sells for more than $4200/MT.[38] Solazyme is moving ahead with building at least two large commercial plants: a facility in Illinois, USA producing approximately 500,000 gallons (1.89 million L) of oil/annum and a facility in Brazil able to ferment over 28 million gallons/annum (105 million L). At 60% concentration, the Brazilian facility alone would theoretically be able to meet about 40% of global myristic acid market.[39]

Solazyme has signed a number of joint ventures and agreements with some of the world's largest sugar, chemical and oleochemical players, including Bunge, Archer Daniels Midland, Dow, Akzonobel and Mitsui. The $20 million Mitsui deal is especially relevant for coconut and palm kernel oil markets since it focuses specifically on the further development of high myristic algal oil.[40] Mitsui has been producing oleochemicals for 20 years through its subsidiary Palm Oleo and is a significant investor in Kuala Lumpur Kepong Berhad (KLK), which owns palm oil and rubber plantations and is the world's largest oleochemical company. On signing the multi-year deal, Mitsui stated that it "looks forward to strengthening its position in the oleochemicals industry through the successful development and commercialization of these novel products."[41] Solazyme also has an agreement with Unilever, one of the world's largest end-users of oleochemical ingredients for production of consumer soaps and detergents. In this way, Solazyme appears to have secured partners all along the supply chain – from initial sugar to final consumer product.

CODEXIS AND LS9: MAKING FATTY ALCOHOLS IN MICROBES

Codexis is a synthetic biology company using computer-based techniques to artificially 'evolve' and re-engineer enzymes and microorganisms.[42] LS9, founded by leading synbio researchers Jay Keasling and George Church, is focused on engineering microbes – primarily *E. coli* – to produce industrial compounds.[43] Both are based in California and both were initially focused on biofuels but are now moving into other markets. Both companies have developed the technology to produce fatty alcohols. According to Codexis, so-called "detergent alcohols" for use in household products represent a $6 billion market worldwide, expected to reach $8 billion in a decade.[44]

While there is a range of different fatty alcohols, the popular C12-14 alcohols, known as lauric alcohols, are usually derived from coconut oil and palm kernel oil. Codexis has developed a microorganism that produces a new lauric alcohol dubbed CodeXol and in collaboration with Chemtex, a subsidiary of Italian chemical company Gruppo M&G, is scaling up production of CodeXol; they aim to reach full-scale commercialisation by 2015.[45] In June 2013, Codexis and Gruppo M&G announced that they had successfully scaled up a process that would transform cellulosic biomass into lauric alcohols.[46] In theory, this would allow Codexis to produce a competitor to coconut- and palm kernel oil-derived detergents using so-called agricultural 'waste' and forest 'residues' as feedstock.

LS9 has agreements with Procter & Gamble[47] and a facility in Florida, USA that produces 135,000 liters of fatty alcohols at a time and has reportedly been producing batches for commercial partners. LS9 plans three 750,000-liter fermenters in Brazil, which could produce 10,000-25,000 MT/year of fatty alcohols, while a large-scale commercial facility is expected (in 2017-2018) to have a capacity of 200,000 MT/year.[48]

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