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Artificial Symbiosis: How Synthetic Biology is Revolutionizing Agriculture

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Original Article

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ABSTRACT

Abstract: Rapid expansion in the emerging field of synthetic biology has to date mainly focused on the microbial sciences and human health. However, the zeitgeist is that synthetic biology will also shortly deliver major outcomes for agriculture. The primary industries of agriculture, fisheries and forestry, face significant and global challenges; addressing them will be assisted by the sector's strong history of early adoption of transformative innovation, such as the genetic technologies that underlie synthetic biology. The implementation of synthetic biology within agriculture may, however, be hampered given the industry is dominated by higher plants and mammals, where large and often polyploid genomes and the lack of adequate tools challenge the ability to deliver outcomes in the short term. Specifically, synthetic biology promises to deliver benefits that increase productivity and sustainability across primary industries, underpinning the industry's prosperity in the face of global challenges.

Aim

To explore how synthetic biology facilitates artificial symbiosis to revolutionize agriculture by enhancing crop productivity, resilience, and sustainability.

Objectives

1) Investigate the concept of artificial symbiosis and its relevance to agriculture. Study the role of synthetic biology in engineering symbiotic relationships between plants and microorganisms.
2) Enhance Crop Productivity Explore synthetic biology tools for improving nutrient uptake through engineered symbiotic microorganisms (e.g., nitrogen-fixing bacteria).

Method: A cross-sectional survey was conducted among 206 dental students, comprising 112 males (22%) and 94 females (78%), including 16 first-year BDS students, 46 second-year BDS students, 25 third-year BDS students, 29 fourth-year BDS students and 90 interns. The survey included 12 questions exploring

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awareness, perceptions, On artificial symbiosis for pre-clinical Curriculum. Responses were analyzed based on gender and year of study using chi-square tests to identify statistically significant differences.

Keywords: Artificial Symbiosis, Agriculture, Genetically Modified Organisms, Crop Productivity, Synthetic Biology, Xeno Transplantation.

Introduction

The intersection of synthetic biology and agriculture is ushering in a new era of innovation, poised to transform how we grow food, manage resources, and sustain the planet. Synthetic biology — the design and engineering of biological systems for useful purposes — offers groundbreaking opportunities to address some of the most pressing challenges in agriculture, from improving crop resilience and yield to reducing environmental impact. By reprogramming the genetic makeup of plants, microbes, and even animals, scientists can create tailored solutions that enhance nutrient content, resist pests and diseases, and thrive under changing climate conditions. As global food demand continues to rise and sustainability becomes increasingly urgent, synthetic biology stands at the forefront, offering transformative possibilities that could redefine the future of agriculture.

Methodology

A) Study design and area: A cross-sectional study was carried out at the tertiary care teaching hospital Khammam.

B) Study population: The health care students including those of I year II year III year IV year and Interns who responded to the offline paper print questionnaire survey.

C) Study Instrument: A self-administered questionnaire was designed based on knowledge attitude and awareness of the shade-matching ability and had a total of 12 questions. Each participant has to fill in their demographic data, such as name, age, and year of study. Participants had to select one option from the answers provided against questions the questions were based on knowledge attitude and awareness among dental students.

D) Pilot study: A pilot study was conducted on a group of students to assess the validity and reliability of the study.

E) Sampling method: The sampling method used is a convenience method.

F) Inclusion criteria: The students who were interested in the study and who were willing to participate.

G) Exclusion criteria: students who are not willing to participate are excluded.

H) Organizing the study: The study was designed in a paper-based version of the self-administered questionnaire of 14 questions focusing on knowledge, and awareness. Includes the sections of demographic data: Name, Age, Sex, and Year of study demographic information and asked to answer all questions by selecting one option from the provided answers. I) Statistical analysis: Data from the filled questionnaire was collected in a tabular form in an Excel worksheet and evaluated for analysis. The analysis was performed by SSPS version 29.

Result

A total of 206 students took part in this with females (78%) and males (22%). Age of the participants ranged from 18-25 years. In this study, females were more likely to demonstrate awareness of Digital dentistry than males. Significantly Interns showed greater familiarity with advanced applications than fourth-year students.

Descriptive Statistics					
	N	Minimum	Maximum	Mean	Std. Deviation
Age	205	18	25	22.26	1.136
Valid N (listwise)	205				

Year of Study		Gender		Total
		Female	Male	
Year of Study	IV BDS	8	21	29
	I BDS	10	6	16
	Intern	61	29	90
	II BDS	6	40	46
	III BDS	9	16	25
Total		94	112	206

Q1

Gender				Year of Study					Total
				Final year	First year	Intern	Second year	Third year	
Female		A	Count	3	4	29	1	4	41
			% of Total	3.2%	4.3%	30.9%	1.1%	4.3%	43.6%
		B	Count	3	0	11	4	3	21
			% of Total	3.2%	0.0%	11.7%	4.3%	3.2%	22.3%
		c	Count	1	0	2	0	0	3
			% of Total	1.1%	0.0%	2.1%	0.0%	0.0%	3.2%
		D	Count	1	6	19	1	2	29
			% of Total	1.1%	6.4%	20.2%	1.1%	2.1%	30.9%
	Total		Count	8	10	61	6	9	94
			% of Total	8.5%	10.6%	64.9%	6.4%	9.6%	100.0%
Male		A	Count	13	4	9	15	7	48
			% of Total	11.6%	3.6%	8.0%	13.4%	6.3%	42.9%
		B	Count	4	0	12	17	4	37
			% of Total	3.6%	0.0%	10.7%	15.2%	3.6%	33.0%
		D	Count	4	2	8	8	5	27

		% of Total	3.6%	1.8%	7.1%	7.1%	4.5%	24.1%
	Total	Count	21	6	29	40	16	112
		% of Total	18.8%	5.4%	25.9%	35.7%	14.3%	100.0%
Total	A	Count	16	8	38	16	11	89
		% of Total	7.8%	3.9%	18.4%	7.8%	5.3%	43.2%
	B	Count	7	0	23	21	7	58
		% of Total	3.4%	0.0%	11.2%	10.2%	3.4%	28.2%
	C	Count	1	0	2	0	0	3
		% of Total	0.5%	0.0%	1.0%	0.0%	0.0%	1.5%
	D	Count	5	8	27	9	7	56
		% of Total	2.4%	3.9%	13.1%	4.4%	3.4%	27.2%
	Total	Count	29	16	90	46	25	206
		% of Total	14.1%	7.8%	43.7%	22.3%	12.1%	100.0%

P Value = 0.120

Q2

Gender			Year of Study					Total
			Final year	First year	Intern	Second year	Third year	
Female	A	Count	0	1	2	1	0	4
		% of Total	0.0%	1.1%	2.1%	1.1%	0.0%	4.3%
	B	Count	3	6	29	1	3	42
		% of Total	3.2%	6.4%	30.9%	1.1%	3.2%	44.7%
	C	Count	2	3	13	2	2	22
		% of Total	2.1%	3.2%	13.8%	2.1%	2.1%	23.4%
	D	Count	3	0	17	2	4	26
		% of Total	3.2%	0.0%	18.1%	2.1%	4.3%	27.7%
	Total	Count	8	10	61	6	9	94
		% of Total	8.5%	10.6%	64.9%	6.4%	9.6%	100.0%
Male	A	Count	0	2	1	3	0	6
		% of Total	0.0%	1.8%	0.9%	2.7%	0.0%	5.4%
	B	Count	12	2	16	15	11	56
		% of Total	10.7%	1.8%	14.3%	13.4%	9.8%	50.0%

	C	Count	3	0	4	5	2	14
		% of Total	2.7%	0.0%	3.6%	4.5%	1.8%	12.5%
	D	Count	6	2	8	17	3	36
		% of Total	5.4%	1.8%	7.1%	15.2%	2.7%	32.1%
	Total	Count	21	6	29	40	16	112
		% of Total	18.8%	5.4%	25.9%	35.7%	14.3%	100.0%
Total	A	Count	0	3	3	4	0	10
		% of Total	0.0%	1.5%	1.5%	1.9%	0.0%	4.9%
	B	Count	15	8	45	16	14	98
		% of Total	7.3%	3.9%	21.8%	7.8%	6.8%	47.6%
	C	Count	5	3	17	7	4	36
		% of Total	2.4%	1.5%	8.3%	3.4%	1.9%	17.5%
	D	Count	9	2	25	19	7	62
		% of Total	4.4%	1.0%	12.1%	9.2%	3.4%	30.1%
	Total	Count	29	16	90	46	25	206
		% of Total	14.1%	7.8%	43.7%	22.3%	12.1%	100.0%

P Value = 0.577

Q3

Gender			Year of Study					Total
			Final year	First year	Intern	Second year	Third year	
Female	A	Count	2	3	19	3	6	33
		% of Total	2.1%	3.2%	20.2%	3.2%	6.4%	35.1%
	B	Count	5	2	20	3	1	31
		% of Total	5.3%	2.1%	21.3%	3.2%	1.1%	33.0%
	C	Count	0	3	9	0	0	12
		% of Total	0.0%	3.2%	9.6%	0.0%	0.0%	12.8%
	D	Count	1	2	13	0	2	18
		% of Total	1.1%	2.1%	13.8%	0.0%	2.1%	19.1%
	Total	Count	8	10	61	6	9	94
		% of Total	8.5%	10.6%	64.9%	6.4%	9.6%	100.0%
Male	A	Count	6	3	5	10	4	28

			% of Total	5.4%	2.7%	4.5%	8.9%	3.6%	25.0%
		B	Count	10	0	13	17	8	48
			% of Total	8.9%	0.0%	11.6%	15.2%	7.1%	42.9%
		C	Count	1	0	4	3	1	9
			% of Total	0.9%	0.0%	3.6%	2.7%	0.9%	8.0%
		D	Count	4	3	7	10	3	27
			% of Total	3.6%	2.7%	6.3%	8.9%	2.7%	24.1%
	Total		Count	21	6	29	40	16	112
			% of Total	18.8%	5.4%	25.9%	35.7%	14.3%	100.0%
Total		A	Count	8	6	24	13	10	61
			% of Total	3.9%	2.9%	11.7%	6.3%	4.9%	29.6%
		B	Count	15	2	33	20	9	79
			% of Total	7.3%	1.0%	16.0%	9.7%	4.4%	38.3%
		C	Count	1	3	13	3	1	21
			% of Total	0.5%	1.5%	6.3%	1.5%	0.5%	10.2%
		D	Count	5	5	20	10	5	45
			% of Total	2.4%	2.4%	9.7%	4.9%	2.4%	21.8%
	Total		Count	29	16	90	46	25	206
			% of Total	14.1%	7.8%	43.7%	22.3%	12.1%	100.0%

P Value = 0.244

Q4

Gender				Year of Study					Total
				Final year	First year	Intern	Second year	Third year	
Female		A	Count	5	4	13	1	2	25
			% of Total	5.3%	4.3%	13.8%	1.1%	2.1%	26.6%
		B	Count	0	0	9	1	2	12
			% of Total	0.0%	0.0%	9.6%	1.1%	2.1%	12.8%
		C	Count	2	6	26	3	2	39
			% of Total	2.1%	6.4%	27.7%	3.2%	2.1%	41.5%
		D	Count	1	0	13	1	3	18

			% of Total	1.1%	0.0%	13.8%	1.1%	3.2%	19.1%
	Total		Count	8	10	61	6	9	94
			% of Total	8.5%	10.6%	64.9%	6.4%	9.6%	100.0%
Male		A	Count	9	3	9	10	4	35
			% of Total	8.0%	2.7%	8.0%	8.9%	3.6%	31.3%
		B	Count	0	1	4	4	3	12
			% of Total	0.0%	0.9%	3.6%	3.6%	2.7%	10.7%
		C	Count	11	2	15	12	7	47
			% of Total	9.8%	1.8%	13.4%	10.7%	6.3%	42.0%
		D	Count	1	0	1	14	2	18
			% of Total	0.9%	0.0%	0.9%	12.5%	1.8%	16.1%
	Total		Count	21	6	29	40	16	112
			% of Total	18.8%	5.4%	25.9%	35.7%	14.3%	100.0%
Total		A	Count	14	7	22	11	6	60
			% of Total	6.8%	3.4%	10.7%	5.3%	2.9%	29.1%
		B	Count	0	1	13	5	5	24
			% of Total	0.0%	0.5%	6.3%	2.4%	2.4%	11.7%
		C	Count	13	8	41	15	9	86
			% of Total	6.3%	3.9%	19.9%	7.3%	4.4%	41.7%
		D	Count	2	0	14	15	5	36
			% of Total	1.0%	0.0%	6.8%	7.3%	2.4%	17.5%
	Total		Count	29	16	90	46	25	206
			% of Total	14.1%	7.8%	43.7%	22.3%	12.1%	100.0%

P Value = 0.290

Q5

Gender				Year of Study					Total
				Final year	First year	Intern	Second year	Third year	
Female		A	Count	0	2	12	2	0	16
			% of Total	0.0%	2.1%	12.8%	2.1%	0.0%	17.0%
		B	Count	2	4	19	2	2	29
			% of Total	2.1%	4.3%	20.2%	2.1%	2.1%	30.9%
		C	Count	4	4	26	2	5	41
			% of Total	4.3%	4.3%	27.7%	2.1%	5.3%	43.6%

		D	Count	2	0	4	0	2	8
			% of Total	2.1%	0.0%	4.3%	0.0%	2.1%	8.5%
	Total		Count	8	10	61	6	9	94
			% of Total	8.5%	10.6%	64.9%	6.4%	9.6%	100.0%
Male		A	Count	3	0	5	7	3	18
			% of Total	2.7%	0.0%	4.5%	6.3%	2.7%	16.1%
		B	Count	3	2	4	12	4	25
			% of Total	2.7%	1.8%	3.6%	10.7%	3.6%	22.3%
		C	Count	14	3	15	16	8	56
			% of Total	12.5%	2.7%	13.4%	14.3%	7.1%	50.0%
		D	Count	1	1	5	5	1	13
			% of Total	0.9%	0.9%	4.5%	4.5%	0.9%	11.6%
	Total		Count	21	6	29	40	16	112
			% of Total	18.8%	5.4%	25.9%	35.7%	14.3%	100.0%
Total		A	Count	3	2	17	9	3	34
			% of Total	1.5%	1.0%	8.3%	4.4%	1.5%	16.5%
		B	Count	5	6	23	14	6	54
			% of Total	2.4%	2.9%	11.2%	6.8%	2.9%	26.2%
		C	Count	18	7	41	18	13	97
			% of Total	8.7%	3.4%	19.9%	8.7%	6.3%	47.1%
		D	Count	3	1	9	5	3	21
			% of Total	1.5%	0.5%	4.4%	2.4%	1.5%	10.2%
	Total		Count	29	16	90	46	25	206
			% of Total	14.1%	7.8%	43.7%	22.3%	12.1%	100.0%

P Value = 0.490

Q6

Gender				Year of Study					Total
				Final year	First year	Intern	Second year	Third year	
Female		A	Count	3	3	17	3	3	29
			% of Total	3.2%	3.2%	18.1%	3.2%	3.2%	30.9%
		B	Count	3	2	13	1	4	23
			% of Total	3.2%	2.1%	13.8%	1.1%	4.3%	24.5%
		C	Count	2	5	31	2	2	42

			% of Total	2.1%	5.3%	33.0%	2.1%	2.1%	44.7%
	Total		Count	8	10	61	6	9	94
			% of Total	8.5%	10.6%	64.9%	6.4%	9.6%	100.0%
Male		A	Count	10	4	12	12	4	42
			% of Total	8.9%	3.6%	10.7%	10.7%	3.6%	37.5%
		B	Count	3	1	5	14	2	25
			% of Total	2.7%	0.9%	4.5%	12.5%	1.8%	22.3%
		C	Count	8	1	12	14	10	45
			% of Total	7.1%	0.9%	10.7%	12.5%	8.9%	40.2%
	Total		Count	21	6	29	40	16	112
			% of Total	18.8%	5.4%	25.9%	35.7%	14.3%	100.0%
Total		A	Count	13	7	29	15	7	71
			% of Total	6.3%	3.4%	14.1%	7.3%	3.4%	34.5%
		B	Count	6	3	18	15	6	48
			% of Total	2.9%	1.5%	8.7%	7.3%	2.9%	23.3%
		C	Count	10	6	43	16	12	87
			% of Total	4.9%	2.9%	20.9%	7.8%	5.8%	42.2%
	Total		Count	29	16	90	46	25	206
			% of Total	14.1%	7.8%	43.7%	22.3%	12.1%	100.0%

P Value = 0.649

Q7

Gender				Year of Study					Total
				Final year	First year	Intern	Second year	Third year	
Female		A	Count	8	6	44	4	6	68
			% of Total	8.5%	6.4%	46.8%	4.3%	6.4%	72.3%
		B	Count	0	4	17	2	3	26
			% of Total	0.0%	4.3%	18.1%	2.1%	3.2%	27.7%
	Total		Count	8	10	61	6	9	94

		% of Total	8.5%	10.6%	64.9%	6.4%	9.6%	100.0%
Male	A	Count	15	5	21	25	11	77
		% of Total	13.4%	4.5%	18.8%	22.3%	9.8%	68.8%
	B	Count	6	1	8	15	5	35
		% of Total	5.4%	0.9%	7.1%	13.4%	4.5%	31.3%
	Total	Count	21	6	29	40	16	112
		% of Total	18.8%	5.4%	25.9%	35.7%	14.3%	100.0%
Total	A	Count	23	11	65	29	17	145
		% of Total	11.2%	5.3%	31.6%	14.1%	8.3%	70.4%
	B	Count	6	5	25	17	8	61
		% of Total	2.9%	2.4%	12.1%	8.3%	3.9%	29.6%
	Total	Count	29	16	90	46	25	206
		% of Total	14.1%	7.8%	43.7%	22.3%	12.1%	100.0%

P Value = 0.398

Q8

Gender				Year of Study					Total
				Final year	First year	Intern	Second year	Third year	
Female		A	Count	1	4	10	2	3	20
			% of Total	1.1%	4.3%	10.6%	2.1%	3.2%	21.3%
		B	Count	3	1	21	1	3	29
			% of Total	3.2%	1.1%	22.3%	1.1%	3.2%	30.9%
		C	Count	4	5	30	3	3	45
			% of Total	4.3%	5.3%	31.9%	3.2%	3.2%	47.9%
	Total		Count	8	10	61	6	9	94
			% of Total	8.5%	10.6%	64.9%	6.4%	9.6%	100.0%
Male		A	Count	6	1	6	22	5	40
			% of Total	5.4%	0.9%	5.4%	19.6%	4.5%	35.7%
		B	Count	1	2	6	10	3	22
			% of Total	0.9%	1.8%	5.4%	8.9%	2.7%	19.6%
		C	Count	14	3	17	8	8	50

			% of Total	12.5%	2.7%	15.2%	7.1%	7.1%	44.6%
	Total		Count	21	6	29	40	16	112
			% of Total	18.8%	5.4%	25.9%	35.7%	14.3%	100.0%
Total		A	Count	7	5	16	24	8	60
			% of Total	3.4%	2.4%	7.8%	11.7%	3.9%	29.1%
		B	Count	4	3	27	11	6	51
			% of Total	1.9%	1.5%	13.1%	5.3%	2.9%	24.8%
		C	Count	18	8	47	11	11	95
			% of Total	8.7%	3.9%	22.8%	5.3%	5.3%	46.1%
	Total		Count	29	16	90	46	25	206
			% of Total	14.1%	7.8%	43.7%	22.3%	12.1%	100.0%

P Value= 0.617

Q9

Gender				Year of Study					Total
				Final year	First year	Intern	Second year	Third year	
Female		A	Count	5	6	31	1	5	48
			% of Total	5.3%	6.4%	33.0%	1.1%	5.3%	51.1%
		B	Count	1	2	13	2	2	20
			% of Total	1.1%	2.1%	13.8%	2.1%	2.1%	21.3%
		C	Count	2	2	17	3	2	26
			% of Total	2.1%	2.1%	18.1%	3.2%	2.1%	27.7%
	Total		Count	8	10	61	6	9	94
			% of Total	8.5%	10.6%	64.9%	6.4%	9.6%	100.0%
Male		A	Count	10	5	15	14	4	48
			% of Total	8.9%	4.5%	13.4%	12.5%	3.6%	42.9%
		B	Count	8	1	3	5	6	23
			% of Total	7.1%	0.9%	2.7%	4.5%	5.4%	20.5%
		C	Count	3	0	11	21	6	41
			% of Total	2.7%	0.0%	9.8%	18.8%	5.4%	36.6%
	Total		Count	21	6	29	40	16	112
			% of Total	18.8%	5.4%	25.9%	35.7%	14.3%	100.0%
Total		A	Count	15	11	46	15	9	96

			% of Total	7.3%	5.3%	22.3%	7.3%	4.4%	46.6%
		B	Count	9	3	16	7	8	43
			% of Total	4.4%	1.5%	7.8%	3.4%	3.9%	20.9%
		C	Count	5	2	28	24	8	67
			% of Total	2.4%	1.0%	13.6%	11.7%	3.9%	32.5%
	Total		Count	29	16	90	46	25	206
			% of Total	14.1%	7.8%	43.7%	22.3%	12.1%	100.0%

P Value = 0.865

Q10

Gender				Year of Study					Total
				Final year	First year	Intern	Second year	Third year	
Female		A		4	6	29	2	5	46
				4.3%	6.4%	30.9%	2.1%	5.3%	48.9%
		B		1	1	18	0	0	20
				1.1%	1.1%	19.1%	0.0%	0.0%	21.3%
		C		3	3	9	4	3	22
				3.2%	3.2%	9.6%	4.3%	3.2%	23.4%
		D		0	0	5	0	1	6
				0.0%	0.0%	5.3%	0.0%	1.1%	6.4%
	Total		Count	8	10	61	6	9	94
			% of Total	8.5%	10.6%	64.9%	6.4%	9.6%	100.0%
Male		A	Count	11	2	13	15	7	48
			% of Total	9.8%	1.8%	11.6%	13.4%	6.3%	42.9%
		B	Count	4	1	7	10	6	28
			% of Total	3.6%	0.9%	6.3%	8.9%	5.4%	25.0%
		C	Count	5	1	9	13	2	30
			% of Total	4.5%	0.9%	8.0%	11.6%	1.8%	26.8%
		D	Count	1	2	0	2	1	6
			% of Total	0.9%	1.8%	0.0%	1.8%	0.9%	5.4%
	Total		Count	21	6	29	40	16	112
			% of Total	18.8%	5.4%	25.9%	35.7%	14.3%	100.0%
Total		A	Count	15	8	42	17	12	94
			% of Total	7.3%	3.9%	20.4%	8.3%	5.8%	45.6%
		B	Count	5	2	25	10	6	48
			% of Total	2.4%	1.0%	12.1%	4.9%	2.9%	23.3%

		C	Count	8	4	18	17	5	52
			% of Total	3.9%	1.9%	8.7%	8.3%	2.4%	25.2%
		D	Count	1	2	5	2	2	12
			% of Total	0.5%	1.0%	2.4%	1.0%	1.0%	5.8%
	Total		Count	29	16	90	46	25	206
			% of Total	14.1%	7.8%	43.7%	22.3%	12.1%	100.0%

P Value = 0.156

Q11

Gender				Year of Study					Total
				Final year	First year	Intern	Second year	Third year	
Female		A	Count	1	3	19	1	1	25
			% of Total	1.1%	3.2%	20.2%	1.1%	1.1%	26.6%
		B	Count	5	5	25	4	2	41
			% of Total	5.3%	5.3%	26.6%	4.3%	2.1%	43.6%
		C	Count	2	1	12	1	4	20
			% of Total	2.1%	1.1%	12.8%	1.1%	4.3%	21.3%
		D	Count	0	1	5	0	2	8
			% of Total	0.0%	1.1%	5.3%	0.0%	2.1%	8.5%
	Total		Count	8	10	61	6	9	94
			% of Total	8.5%	10.6%	64.9%	6.4%	9.6%	100.0%
Male		A	Count	3	3	10	17	1	34
			% of Total	2.7%	2.7%	8.9%	15.2%	0.9%	30.4%
		B	Count	16	3	12	12	9	52
			% of Total	14.3%	2.7%	10.7%	10.7%	8.0%	46.4%
		C	Count	2	0	6	9	4	21
			% of Total	1.8%	0.0%	5.4%	8.0%	3.6%	18.8%
		D	Count	0	0	1	2	2	5
			% of Total	0.0%	0.0%	0.9%	1.8%	1.8%	4.5%
	Total		Count	21	6	29	40	16	112
			% of Total	18.8%	5.4%	25.9%	35.7%	14.3%	100.0%
Total		A	Count	4	6	29	18	2	59
			% of Total	1.9%	2.9%	14.1%	8.7%	1.0%	28.6%
		B	Count	21	8	37	16	11	93

			% of Total	10.2%	3.9%	18.0%	7.8%	5.3%	45.1%
		C	Count	4	1	18	10	8	41
			% of Total	1.9%	0.5%	8.7%	4.9%	3.9%	19.9%
		D	Count	0	1	6	2	4	13
			% of Total	0.0%	0.5%	2.9%	1.0%	1.9%	6.3%
	Total		Count	29	16	90	46	25	206
			% of Total	14.1%	7.8%	43.7%	22.3%	12.1%	100.0%

P Value = 0.534

Q12

Gender				Year of Study					Total
				Final year	First year	Intern	Second year	Third year	
Female		A	Count	0	2	5	0	1	8
			% of Total	0.0%	2.1%	5.3%	0.0%	1.1%	8.5%
		B	Count	2	2	7	1	1	13
			% of Total	2.1%	2.1%	7.4%	1.1%	1.1%	13.8%
		C	Count	4	2	21	0	2	29
			% of Total	4.3%	2.1%	22.3%	0.0%	2.1%	30.9%
		D	Count	2	4	28	5	5	44
			% of Total	2.1%	4.3%	29.8%	5.3%	5.3%	46.8%
	Total		Count	8	10	61	6	9	94
			% of Total	8.5%	10.6%	64.9%	6.4%	9.6%	100.0%
Male		A	Count	1	0	1	9	1	12
			% of Total	0.9%	0.0%	0.9%	8.0%	0.9%	10.7%
		B	Count	4	3	7	6	3	23
			% of Total	3.6%	2.7%	6.3%	5.4%	2.7%	20.5%
		C	Count	3	1	3	14	4	25
			% of Total	2.7%	0.9%	2.7%	12.5%	3.6%	22.3%
		D	Count	13	2	18	11	8	52
			% of Total	11.6%	1.8%	16.1%	9.8%	7.1%	46.4%
	Total		Count	21	6	29	40	16	112
			% of Total	18.8%	5.4%	25.9%	35.7%	14.3%	100.0%
Total		A	Count	1	2	6	9	2	20
			% of Total	0.5%	1.0%	2.9%	4.4%	1.0%	9.7%

		B	Count	6	5	14	7	4	36
			% of Total	2.9%	2.4%	6.8%	3.4%	1.9%	17.5%
		C	Count	7	3	24	14	6	54
			% of Total	3.4%	1.5%	11.7%	6.8%	2.9%	26.2%
		D	Count	15	6	46	16	13	96
			% of Total	7.3%	2.9%	22.3%	7.8%	6.3%	46.6%
	Total		Count	29	16	90	46	25	206
			% of Total	14.1%	7.8%	43.7%	22.3%	12.1%	100.0%

P-Value= 0.565

Discussion

Identification of the genes essential for a minimal bacterial genome and related projects such as genome transplantation facilitated complex projects synthesizing whole bacterial genomes and transplanting them back into bacterial cells. However, synthetic genomics is just one example of synthetic biology. Metabolic engineering has been galvanized by the advances in genome technologies, with industrial scale production of Genes 2018, 9, 341, 341 2 of 17 complex metabolites from heterologous and at times de novo pathways becoming common. New biosensors (genetically encoded sensors for biological or non-biological stimuli) and increasingly complex genetically encoded circuits are being realized for a growing number of applications, there are many other emerging fields. Primary industries such as agriculture, fisheries, and forestry, have historically benefited directly from advances in genetic research. The sector has a strong history of rapid uptake of transformative innovation, for example worldwide between 1996 and 2013 more than 110 and 195 million tons of additional soybean and maize production, respectively, was attributed to positive yield effects of genetic technologies. As an early adopter, the global agriculture industry is expected to be one of the major beneficiaries of synthetic biology. The sector also faces significant challenges including increasing global population and technological innovations are key to meeting concomitant increases in demand for food and agricultural products. Synthetic biology can provide tools to address many of these challenges and as an early adopter, the industry is likely to be a major beneficiary of the fast-evolving global bioeconomy. One interpretation of synthetic biology could be that it is a reductionist view of biology through the lens of an engineer. The genetics of this system are broken down into a gene that confers perception of light, and a metabolic pathway for carbohydrates. When the light genes are activated, the cell activates the carbohydrate synthesis pathway, feeding the rest of the plant. This concept can be extrapolated to a myriad of potentially exploitable systems in biology. The first element of a genetic circuit, biosensors (genetically-encoded sensors), are a potentially transformative field of synthetic biology with promise for agriculture in their own right. Inverters, XORs (exclusive OR gates) transducers, oscillators, and many more logic operations can be translated into biological systems all with different potential outcomes; together these create a highly powerful toolbox for biological design. The major challenge to the implementation of synthetic biology in agriculture is the time and expense involved in the propagation, transformation, and screening of higher plants. While there has been a boost to plant biotechnology following new developments such as CRISPR/Cas9-mediated gene editing, speed breeding, the sequencing of key genomes, and the growth of synthetic biology as a field, challenges remain. For instance, the immense size of plant genomes and their polyploidy (wheat, for example,

has a hexaploid > 15 Gb genome have now limited the effectiveness of site-specific genetic manipulation. In the mammalian context, CRISPR/Cas9 has been used in a whole-genome approach by a process called multiplexing, whereby one targeting sequence corresponds to multiple sites across a genome. All porcine endogenous retroviruses (PERV) were removed from the pig genome using multiplexed CRISPR/Cas9. The resulting PERV-free fibroblasts were used in somatic cell nuclear transfer, generating PERV-inactivated whole pigs. While the overall goal of this work was to ensure healthy pig tissues for xenotransplantation, there are also some broad-reaching implications of this work relevant to food safety and livestock health. Another genome-scale technology, genetic 'recoding', removes all instances of a particular codon for an amino acid from a genome. The codon can then be used in the new organism to specify different, novel, and unnatural amino acids. The concept has been demonstrated to be robust, with over 1557 leucine codons replaced across 176 genes in a Salmonella typhimurium strain, with no impact on cell growth. Furthermore, recoding has been demonstrated as a potential mechanism to confer viral pathogen resistance by blocking effective horizontal gene transfer, however, the more significant implication of this technology is the control of the flow of genetic information. Genetically encoded 'speciation' in yeast, is part of a larger push towards improving biocontainment using synthetic biology, with broad-reaching implications on mitigating potential unforeseen consequences of the release of synthetic organisms. The promise associated with synthetic biology does come with risks that must be identified, mitigated, and managed. Regulatory frameworks need to manage risks and ensure an appropriate balance between the industry's enthusiasm to access new technologies and any concerns within the community more broadly. There is a lack of consistency in the approach to regulation of GMOs (genetically modified organisms) internationally, Frameworks differ significantly between countries, and most have failed to keep pace with the rapid development of new genetic technologies. Many touch on topics related to synthetic biology but few nominate synthetic biology directly. Synthetic biology and gene editing are consistently amongst the technologies most frequently drawn to the attention of regulators. Gene drives hold significant and immediate promise for integrated pest management, given their significant potential to spread traits across a breeding population. However, potential issues such as the incorrect identification of favorable alleles, the spread of gene drives from farmed populations to natural populations, and the mutation of gene drive elements all pose unique concerns and potentially require more significant risk assessment prior to, and containment and record keeping during implementation. Beyond regulation, a secondary constraint to all transformative technologies is the reality that early innovations are not necessarily published in the public domain. This is not unique to synthetic biology and reflects that innovations relating to potentially profitable endeavors are likely to be patented and then commercialized. This impacts 'freedom to operate' and may help explain the paucity of manuscripts in the international literature that deal with synthetic biology in agriculture. We note that the sales of fertilizers and agricultural chemicals are worth $160 billion and $40 billion a year respectively and the market value of companies in the field such as Indigo Ag, demarcating research around water and nitrogen use efficiency, and Gingko Bioworks working on microbial fragrances, nutraceuticals, flavourings, and agriculture, and eligo biosciences which works working in the field of microbiome engineering. The intellectual property footprint of these well-funded companies can pose barriers to the dissemination of synthetic biology in the scientific community, whilst regulation and deregulation may stymie access to the technology in the agricultural sphere.

Conclusion

Artificial symbiosis, driven by advancements in synthetic biology, represents a groundbreaking

approach to revolutionizing agriculture. By engineering mutually beneficial relationships between plants and microorganisms, synthetic biology enables innovations that significantly enhance crop productivity, resilience, and sustainability. Engineered microbes can improve nutrient uptake, bolster resistance to pests and diseases, and adapt plants to changing climates, reducing reliance on chemical fertilizers and pesticides.

Moreover, these innovations promote eco-friendly farming practices, addressing critical challenges such as soil degradation, water scarcity, and climate change. While the potential of artificial symbiosis is immense, careful attention must be paid to ethical, ecological, and regulatory considerations to ensure safe and sustainable deployment.

In conclusion, artificial symbiosis holds the promise of transforming agriculture into a more sustainable and resilient system, offering solutions to feed the growing global population while protecting the environment.

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