Cooking and processing of seaweed to improve consumer acceptance, protein digestion and nutrient bioavailability

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Introduction

- Seaweed has long been used as a food by Māori in New Zealand (NZ), and in Singapore (SG).
- Raw seaweed can be hard for humans to digest, and consequently proteins and other nutrients can remain locked within the seaweed structure.
- The ability to digest seaweed may differ between populations, e.g. Singaporeans vs New Zealanders, due to differences in the gut microbiome.
- In this collaborative project, we focus on *Undaria pinnatifida* and *Ulva spp* as minimally processed alternative protein wholefoods.
- Hypothesis: Innovative cooking will enhance the digestibility and nutritional value of *Undaria* and *Ulva* and also result in desirable flavour profiles that appeals to consumers.

Aim

To generate new knowledge about human digestion, nutritional availability, flavour and health benefits of seaweed as a whole food.

Methodology

- Seaweed has been collected in both NZ (*Undaria pinnatifida* and *Ulva* spp) and SG (*Ulva* spp) following a standardised collection, drying and storage protocol (**Fig. 1A**).
- Two high-protein prototype foods, catering to SG and NZ palates respectively, are under development by top-end chef Dale Bowie (**Fig. 1B**). All seaweed formats will be characterised nutritionally, with a focus on proteins and amino acids.

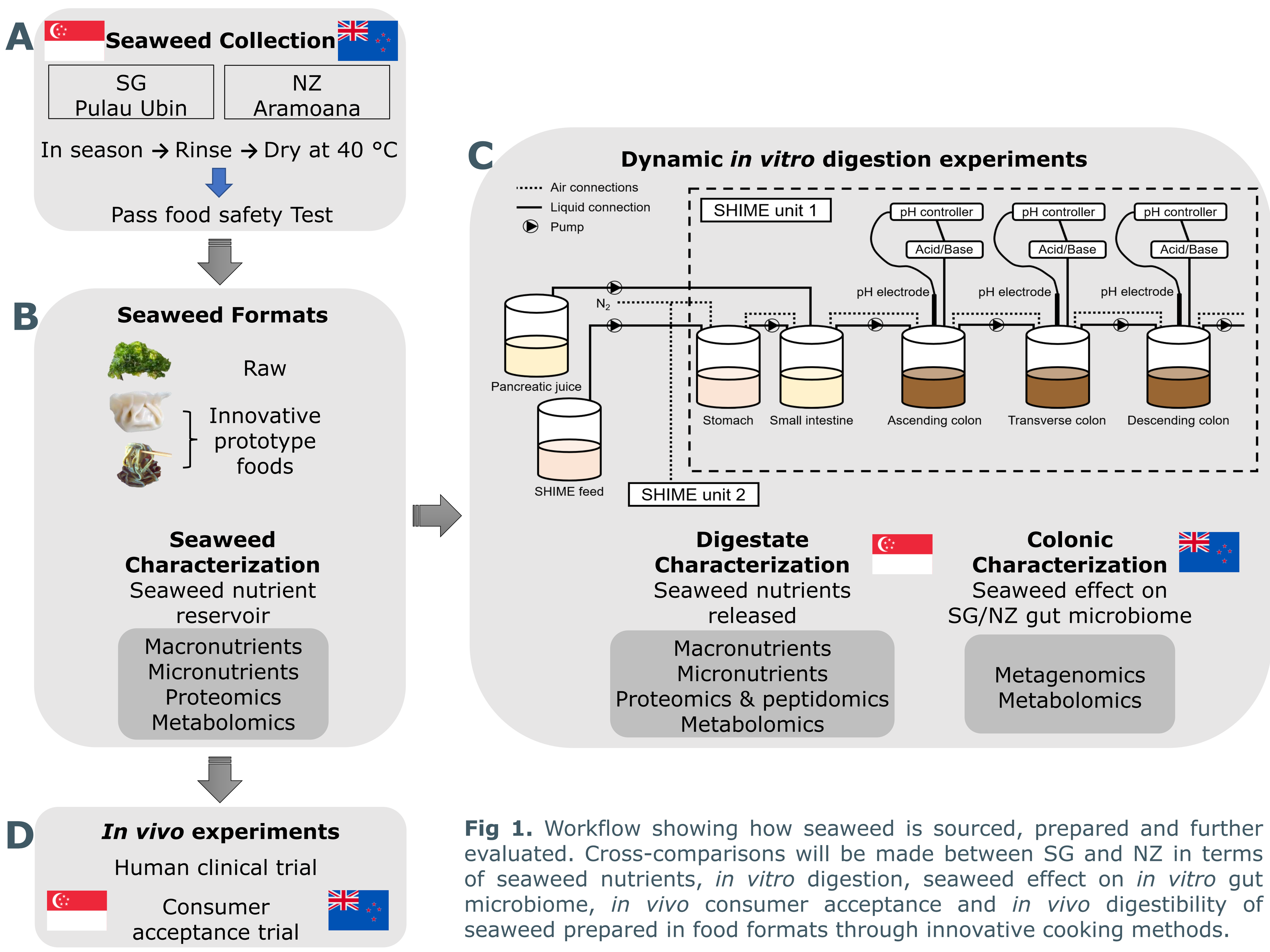

Fig 1. Workflow showing how seaweed is sourced, prepared and further evaluated. Cross-comparisons will be made between SG and NZ in terms of seaweed nutrients, *in vitro* digestion, seaweed effect on *in vitro* gut microbiome, *in vivo* consumer acceptance and *in vivo* digestibility of seaweed prepared in food formats through innovative cooking methods.

- Foods will be digested and fermented in the Simulated Human Intestinal Microbial Ecosystem (SHIME®) *in vitro* digestion system. Omics techniques will be used to assess protein digestibility, release of bioactive compounds, and modulation of the gut microbiome (**Fig. 1C**).
- Protein digestibility and nutritional availability of seaweed prototype foods may then be assessed *in vivo* in a human clinical trial, while consumer acceptance of the prototype foods will be assessed in trials conducted in both NZ and SG (**Fig. 1D**).

Results to date and discussion

- Food safety profiling of *Undaria pinnatifida* and *Ulva* spp has been completed (**Table 1**). While iodine levels are relatively high in SG *Ulva* and NZ *Undaria*, methods can be applied to remove iodine from the seaweed prior to cooking.

Table 1. Heavy metals and iodine safety screening test results of SG and NZ seaweeds, food standards specific for seaweed and national recommended nutrient intake. Red numbers indicate values are higher than the allowable or recommended intake values.

Heavy Metals and Iodine (mg/100 g dry sample basis)						
Seaweed	**Total As**	**Inorganic As**	**Cd**	**Pb**	**Hg**	**I**
NZ *Undaria pinnatifida*	0.842	ND	0.038	0.132	0.002	1.8
SG *Ulva* spp	0.411	0.01	0.007	0.129	0.0007	1.8
NZ food standards[1]	-	1	-	-	-	-
NZ upper limit[2]	-	-	-	-	-	1.1
SG food standards[3]	-	0.200	0.200	0.200	0.005	-
SG daily allowance[4]	-	-	-	-	-	0.1

Table 2. Essential amino acid (EAA) and non-essential amino acid (NEAA) composition of proteins extracted from *Ulva* spp from SG and NZ, and *Undaria pinnatifida* from NZ.

Amino acids (g/100g dry sample basis)			
Samples	**EAA**	**NEAA**	**Total Protein**
NZ *Ulva* spp	20.81	32.77	53.58
SG *Ulva* spp*	6.78	11.14	17.92
NZ *Undaria pinnatifida*	1.59	3.29	4.88
Egg Whole	5.63	7.04	12.67
Soy Tofu	8.98	12.30	21.28

*Freeze-thawed once.

- Methods have been developed and validated for extraction of proteins for proteomics, total protein determination and fast metabolite screening using rapid evaporative ionization mass spectrometry (REIMS).
- Total protein content was higher in *Ulva* spp from both SG and NZ compared to NZ *Undaria*, consistent with literature reported trends (**Table 2**). Although the total EAA in *Ulva* spp and *Undaria pinnatifida* can be comparable to common animal and plant protein sources such as egg and soy tofu, different protein extraction methods can impact the quantification of amino acids.

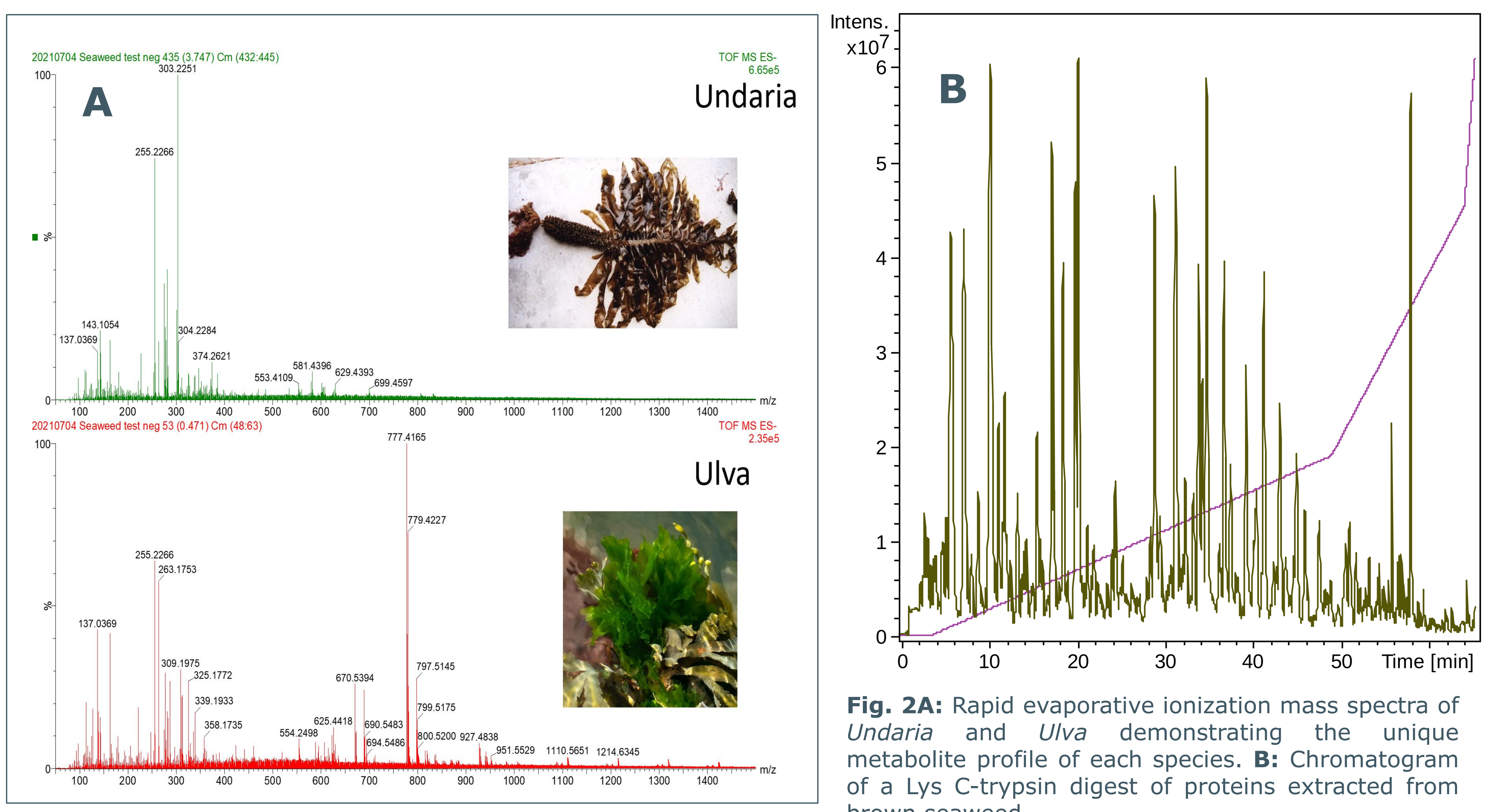

Fig. 2A: Rapid evaporative ionization mass spectra of *Undaria* and *Ulva* demonstrating the unique metabolite profile of each species. **B:** Chromatogram of a Lys C-trypsin digest of proteins extracted from brown seaweed.

- Over 2,000 (**Fig. 2A**) metabolite features and 450 proteins (**Fig. 2B**) were detected in the seaweed samples.

Conclusions and next steps

- Pre-treatment of seaweed prior to cooking and/or adjustment of serving size will be necessary to meet food safety requirements.
- Proteomics and metabolomics reveal features that distinguish seaweed species for further characterization.
- Next steps include *in vitro* digestion and human studies of prototype foods.

References:
1. Australia New Zealand Food Standards Code Schedule 19 Maximum Levels of Contaminants and Natural Toxicants (2022); 2. National Health and Medical Research Council Nutrient Reference Values for Australia and New Zealand (2006); 3. Singapore Statues Online Incidental Constituents in Foods (2023); 4. Singapore Health Promotion Board Nutrition Labelling Guidelines (2020).

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