perennia

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Post-Harvest Handling Guide for Cultivated Kelp in Nova Scotia

Ecology Action Centre

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Ecology Action Centre

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DEFINITIONS

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Biological hazards include microorganisms such as bacteria, viruses, parasites, fungi (yeast and moulds) that can cause foodborne illness if they or their toxins are ingested.

Blanching is the process of submersing a food product into hot water for a short duration and immediately followed by submersion into cold water.

Chemical hazards include naturally occurring chemical toxins (i.e., histamine, biotoxins), intentionally added chemicals (i.e., processing aids, additives), unintentional chemicals (i.e., cleaners, lubricants, etc.) and allergens that may be present as an ingredient or through cross-contact throughout the entire processing chain.

Chilling is the process of cooling a product to a temperature approaching that of melting ice.

Drying is the process of exposing products to open air or mechanically circulated air (CAC, 2018).

Freezing is a preservation process whereby foods are subjected to a freezing process that causes the internal product temperature to reach -18 °C or colder (CAC, 2017).

Hazard is a biological, chemical, or physical agent in food or the condition of food with the potential to cause an adverse health effect (FAO and WHO, 2020).

Grinding is the process of breaking large particles into smaller particles by the application of physical forces.

Packaging is the act of enclosing foods within food contact materials for storage, distribution and sale.

Physical hazards are extraneous matter, foreign objects, physical matter not normally found in food that may cause illness (including trauma) or injury, such as bones, glass, plastic, metal, wood, animal droppings or insects.

Salting is the process of mixing a food product with food-grade salt in a manner that drives the uptake of salt into the food product (CAC, 2018).

Cutting is the process of transforming a product into smaller pieces with a consistent dimension.

Washing is the process of physically removing dirt, debris and some bacteria that can cause illness but does not kill bacteria (USDA, 2022).

Water activity is a food attribute that indicates the water available in that food to be used by bacteria and participate in chemical reactions.

1.0 INTRODUCTION

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This resource was developed to provide quality, safety and technical guidance to key stakeholders involved in cultivated kelp supply chains, including farmers, processors, restaurants and food businesses involved in the utilization or development of food products from cultivated kelp.

As an alternative to feed and agricultural products, there is a growing demand to use kelp as food or food ingredients. Interest in kelp cultivation is also growing throughout the Maritimes region, and species of cultivation interest include sugar kelp (*Saccharina latissima*), horsetail kelp (*Laminaria digitata*) and winged kelp (*Alaria esculenta*).

Seaweed processing capacity for the diversity of kelp product forms suited for food use is currently limited throughout Nova Scotia. With the anticipation of increased demand for kelp processing, the Ecology Action Centre sought to minimize barriers to entry by providing guidance on the handling and processing of cultivated kelp.

The production of kelp for food-use differs from processing kelp marketed as a bulk commodity (unprocessed material), as animal feed, or as an extract. Both cultivation practices and strategies adopted for handling and processing play an important role in producing safe and high-quality kelp-based food products. It is the responsibility of the producers to ensure products comply with the quality and safety requirements of customers, Health Canada and the Canadian Food Inspection Agency.

1.1 NAVIGATING THIS RESOURCE

Whether you are a farmer, processor, food business, restaurant, or service provider throughout the supply chain, sections of this resource may not directly apply to your work. For a recommendation on the contents of this resource most applicable to different stakeholder groups, see Table 1.

Table 1. Navigational guide to different stakeholders involved in the production of kelp-based foods.

Stakeholder	Recommended Reading
Farmer	Section 2.0 – Biology Section 3.0 – Regulatory Section 4.2.1 – 4.2.3 Kelp Hazards Section 5.1 – 5.2 Quality Attributes and Considerations during Harvesting
Processor	Section 2.0 – Biology Section 3.0 – Regulatory Section 4.0 – Kelp Hazards Section 5.0 – Manufacturing Kelp-Based Food Products Section 6.0 – Food Labelling
Food Business	Section 2.0 – Biology Section 3.0 – Regulatory Section 4.0 – Kelp Hazards Section 6.0 – Food Labelling
Restaurant/ Chef	Section 2.0 – Biology Section 5.0 – Manufacturing Kelp-based Food Products

2.0 BIOLOGY

Seaweed, or macroalgae, is a highly diverse family of marine plants found globally and broadly classified by their pigmentation (green, red and brown). There are over 2000 species of brown algae, but the genera *Laminaria/ Saccharina* (referred to as kelps) and *Undaria* (referred to as wakame) receive the most interest in cultivation. *Alaria esculenta* belongs to the order *Laminariales*, which also includes species sometimes referred to as kelps.

2.1 KELP ANATOMY

Kelp anatomy is generally consistent across all species. Each plant contains a **holdfast**, a **stipe** and a **blade**. The combination of stipe and blade is referred to as the **frond** or **thallus** (**Figure 1**).

Winged kelp (*Alaria esculenta*) is distinguished by the single blade with midrib down the center and the presence of blades attached to the long stipe.

Horsetail kelp (*Laminaria digitata*) is distinguished by a short stipe and multiple finger-like blades.

Sugar kelp (*Saccharina latissima*) is distinguished by a short stipe and a wrinkled blade with a thicker center portion referred to as sorus tissue.

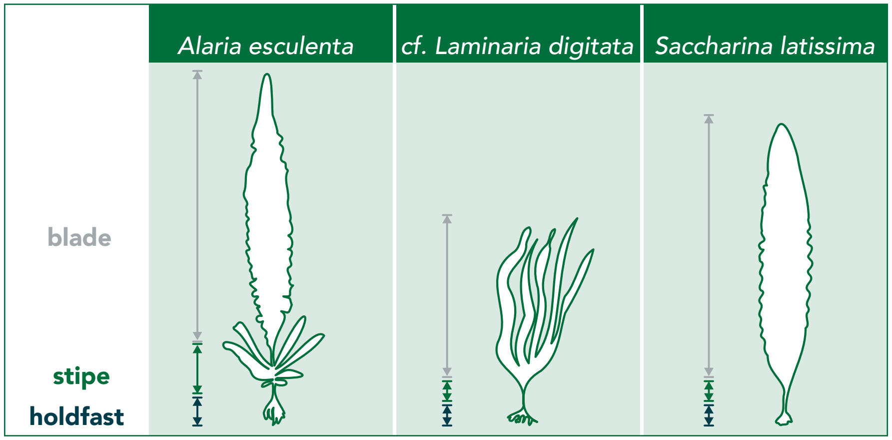

Figure 1. Anatomy of Winged kelp (Alaria esculenta), Horsetail kelp (Laminaria digitata) and Sugar kelp (Saccharina latissima) (Adapted from Ronowicz et al., 2022).

All seaweed contains photosynthetic pigments that determine their colour. Brown algae uniquely contain the pigments chlorophyll c and fucoxanthin. They also tend to grow much larger, in both length and thickness, than either green or red algae. Brown seaweeds also have diverse anatomies and growth characteristics that influence their suitability for cultivation and different end-use applications.

2.2 KELP NUTRIENT COMPOSITION

Seaweed is composed of macronutrients (carbohydrates, proteins, fats, ash) and micronutrients (minerals, vitamins, polyphenols, carotenoids). The nutrient composition of kelp species is variable, influenced by genetic differences between species, geographic and environmental factors such as seawater chemistry and climatological differences at farm sites. Table 2 outlines a range of reported nutrient values for different kelp species.

All pre-packaged foods must contain a Nutrition Facts table (NFt) on their label (Section 6.0), and the represented nutrient values must be accurate to within 20% of the true value. Chemical testing should be performed to verify the nutrient composition of kelp produced from different areas to understand the potential risk of comingling kelp grown from different areas on misrepresenting the food.

Table 2. Nutrient composition of kelps (Adapted from Pereira et al., 2011, Schiener et al., 2015, Stévant et al., 2017, and Akomea-Frempong, 2022).

Nutrient	Amount (g / 100 g)		
	Saccharina latissima	***Alaria esculenta***	***Laminaria digitata***
Moisture (w.b.)	83 – 90	83 – 87	76 – 90
Protein (d.b.)	5 – 26	9 – 20	5 – 15
Lipid (d.b.)	0.5 – 1.1	1.0 – 2.0	0.3 – 3.0
Ash (d.b.)	17 – 43	24 – 40	25 – 45
Carbohydrate (d.b.)	46 – 61	40 – 51	48 – 61
Alginate	20 – 35		
Mannitol	2 – 19		
Laminarin	0 – 33		
Cellulose	10 – 15		

w.b. – wet basis; d.b. – dry basis, proportion in the absence of moisture

Kelp is also a source of bioactive and functional compounds, including alginates, fucoidan, phycobiliproteins, phlorotannins, fucoxanthin, fucosterols and omega-3 fatty acids that have ranging applications for food and health promotion. These compounds are desirable for seaweeds transformed into extracts or kelp ingredients with functional activity.

2.2.1 SEASONAL VARIATION OF MACRONUTRIENTS

The composition of kelp varies throughout the growing season. Understanding this variability can inform cultivation and harvest planning strategies and guide the optimal use of the resource for different end products.

MOISTURE

Water is the largest component of fresh kelp. The moisture content of living kelp peaks in winter from January to April, then progressively declines until September. All non-water components are collectively referred to as dry solids.

CARBOHYDRATES

Carbohydrates are the primary component of kelp dry solids, representing 60 to 84% of the dry weight. Cellulose, alginate, laminarin, mannitol and fucoidan are the individual carbohydrates found in the highest abundance.

Alginates are responsible for the gelling function of kelp and contributes to the slimy texture. It is found most abundantly during the summer but ranges from 5 to 35% throughout the year. Laminarin and mannitol function as energy stores and accumulate from July to October, when photosynthetic mechanisms are most active. These energy stores are progressively depleted from October to May as photosynthesis slows, yet metabolic demands persist. The proportion of cellulose levels does not change seasonally (Schiener et al., 2015; Zhang and Thomsen, 2019).

The carbohydrate content has an important influence on the utility of each species for different food applications. High alginate contents may contribute to sliminess, difficulties in processing and influences the texture of both fresh and rehydrated products. Mannitol is a sugar alcohol that contributes to the sweetness of dried kelps. It can form a white powder on the surface of dried kelp blades that may or may not be desirable.

PROTEIN

Brown algae generally measure lower in protein content than both red and green algae.

Protein levels in kelp also change seasonally, decreasing from July to October as carbohydrate contents increase, but increases with moisture from January to April. The overall protein content also differs between kelp species. *Alaria esculenta* measures the highest, and *L. digitata* measures the lowest (Healy et al., 2022). *Alaria esculenta* also measured double the content of glutamic acid and aspartic acid, the primary amino acids responsible for umami flavour, making *A. esculenta* an ideal ingredient in a plant-based meat alternative over other kelp species.

ASH

Ash content represents the total mineral content, and kelp contains high contents relative to terrestrial plants. Ash content is represented by, in order of decreasing abundance, potassium, sodium, calcium, magnesium, iodine, strontium, iron, arsenic, aluminum, zinc and titanium. Potassium is a reliable indicator of overall ash content.

Total ash content and elemental composition differs between species (Schiener et al., 2015; Kreissig et al., 2021). All species show seasonal variability, peaking in the winter from December to April and declining progressively until September. Ash content can effectively double in concentration throughout this cycle, yet potassium and sodium are individually responsible for these changes.

LIPIDS

Total lipid content and fatty acid composition are characteristics of interest for kelp fats. There are differences between kelp species, influenced by environmental conditions at the farm and changes throughout the growing season.

As an adaptation to cold water conditions, kelp increases the proportion of unsaturated fatty acids (Barbosa, 2020). Total lipid content peaks in the winter from November to April and reaches a minimum in the summer from June to August. However, in *S. latissima*, when total lipids measured the highest over the growing season, the omega-3 content as EPA and DFA were detected at their minimum concentration (Marinho, 2015).

Saccharina latissima grown in deeper (and colder) waters also measured higher total lipid content, and lipids were not equally distributed between the stipes and blades. Blades contained more total lipids and omega-3 fatty acids than stipes, whereas stipes contained higher amounts of omega-6 and omega-9 fatty acids (Barbosa, 2020).

2.3 KELP POST-HARVEST PHYSIOLOGY

RESPIRATION

Under normal growth conditions, seaweed, like all plants, relies on sunlight and carbon dioxide to produce and store energy in the form of carbohydrates via photosynthesis. Seaweed remains alive after harvest but adapts by reversing its metabolism from photosynthesis to respiration, where instead, oxygen and stored energy reserves are consumed, and heat is generated. Without a mechanism to produce new energy, seaweed dies once energy reserves are exhausted and spoilage processes begin.

Respiration relies on consistent access to oxygen. When oxygen is in limited supply, seaweed can still utilize the energy from available carbohydrates via fermentation. Fermentation consumes simple carbohydrates to produce carbon dioxide and alcohol or acid, leading to undesirable sensory changes in the appearance and flavour of seaweed intended for food use. Additionally, poor ventilation of harvested kelp may allow carbon dioxide to accumulate, which has also been found to generate undesirable sensory and physical changes.

In other vegetables, there is a strong relationship between the respiration rate and remaining storage life. To maximize the shelf-life of cultivated seaweed, post-harvest processes that control temperature and respiration should be implemented.

Cultivated sugar kelp harvested in spring stops respiring after nearly 7 days post-harvest when stored under chilled conditions and has an overall shelf-life of 7 to 9 days.

3.0 REGULATORY CONSIDERATIONS

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The harvest, processing and sale of cultivated seaweed are subject to regulations at both federal and provincial levels. The Nova Scotia Fisheries and Coastal Resource Act is the legislation that gives roles and responsibilities to the Nova Scotia Department of Fisheries and Aquaculture (NSDFA), and the Aquaculture License and Lease Regulations outlines the rights, duties, obligations and responsibilities of aquaculture entities.

For these acts and regulations, fish products refer to fishery resources and any parts, products, or by-products derived from fishery resources, and includes sea plants. Sea plants refer only to fucoids (rockweeds) and laminarians (kelps), but not *Chondrus crispus*, dulse or eel-grass.

The following requirements must be in place to legally produce kelp products as food for commercial sale, and is summarized using a decision tree in **Figure 2**:

LEASE FOR FARM SITE AND LICENSE TO CULTIVATE SEA PLANTS - Provincial (NSDFA)

Relevant Stakeholders: Kelp Farmers

Cultivated sea plants from Nova Scotia intended for food use must originate from an approved aquaculture lease site that is operated by an aquaculture license holder for the species indicated on the license (Part V, Fisheries and Coastal Resource Act). Aquaculture licenses issued by NSDFA include permissions to harvest the cultivated aquaculture product from the aquaculture lease area. To harvest any other marine plants from crown waters within NS, contact both NSDFA and DFO to determine licensing requirements.

LICENSE TO BUY SEA PLANTS - Provincial (NSDFA)

Relevant Stakeholders: Food Businesses, Kelp Processor

Sea plants, cultivated or wild, harvested by a permit-holder, may be purchased only by entities licensed to buy fish products (Part VII, Fisheries and Coastal Resource Act).

LICENSE TO PROCESS SEA PLANTS - Provincial (NSDFA)

Relevant Stakeholders: Kelp Processors

Sea plants, whether cultivated or wild, domestically produced or imported, may be processed only by entities licensed to process fish products (Part VII, Fisheries and Coastal Resource Act). Though not specified within these Acts or Regulations, processing commonly refers to any activity that transforms the raw material, including, but not limited to, chilling, washing, cleaning, slicing, chopping, blanching, freezing, drying, grinding, packaging and storing of sea plants.

AUTHORIZATION TO MARKET SEAWEED FOR FOOD USE - Federal (Health Canada)

Relevant Stakeholders: Food Businesses

A novel food means any food that does not have a history of safe use as a food in Canada or that has been manufactured, prepared, preserved, or packed by a process that has not been previously applied to that food and causes the food to undergo a major change (Division 28, Food and Drug Regulations). Novel foods are not permitted for sale to the public until they receive market authorization from the Minister of Health. Non-novel foods are permitted for sale as food and food-ingredients and do not require a safety assessment by Health Canada.

As of February 2023, both *Laminaria digitata* (Kombu kelp) and *Alaria esculenta* (wakame kelp or brown seaweed) in whole or minimally processed formats are included on the List of non-novel determinations for food and food ingredients, whereas *Saccharina latissima* (sugar kelp) is not. In contrast, the EU novel foods catalogue considers Laminaria saccharina (synonymous with *Saccharina latissima*) as non-novel and access to the market is not restricted by comparable EU novel foods regulations.

LICENSE TO PRODUCE FOODS SOLD INTERPROVINCIALLY OR INTERNATIONALLY - Federal (CFIA)

Relevant Stakeholders: Kelp Processors, Food Businesses

To prepare foods within a processing facility that are intended for human consumption and either interprovincial or international sale, companies must be licensed under Safe Food for Canadians by the Canadian Food Inspection Agency. These processors must prepare, keep and maintain a Preventive Control Plan (PCP) that is based on demonstrating Good Manufacturing Practices (GMP) and Hazard Analysis Critical Control Point (HACCP) principles.

Products not intended for sale outside of Nova Scotia or used for non-food application do not require a Safe Food for Canadians license, but may require the processor to follow GMPs.

PERMIT TO PRODUCE FOODS FOR COMMERCIAL SALE WITHIN NS - Provincial (NSDECC)

Relevant Stakeholders: Food Businesses, Restaurants/Chefs

To operate a food service facility or any facility from which foods are sold, whether permanently or only occasionally, a food establishment permit is required.

REGULATORY REQUIREMENTS FOR COMMERCIAL FOOD PRODUCTION

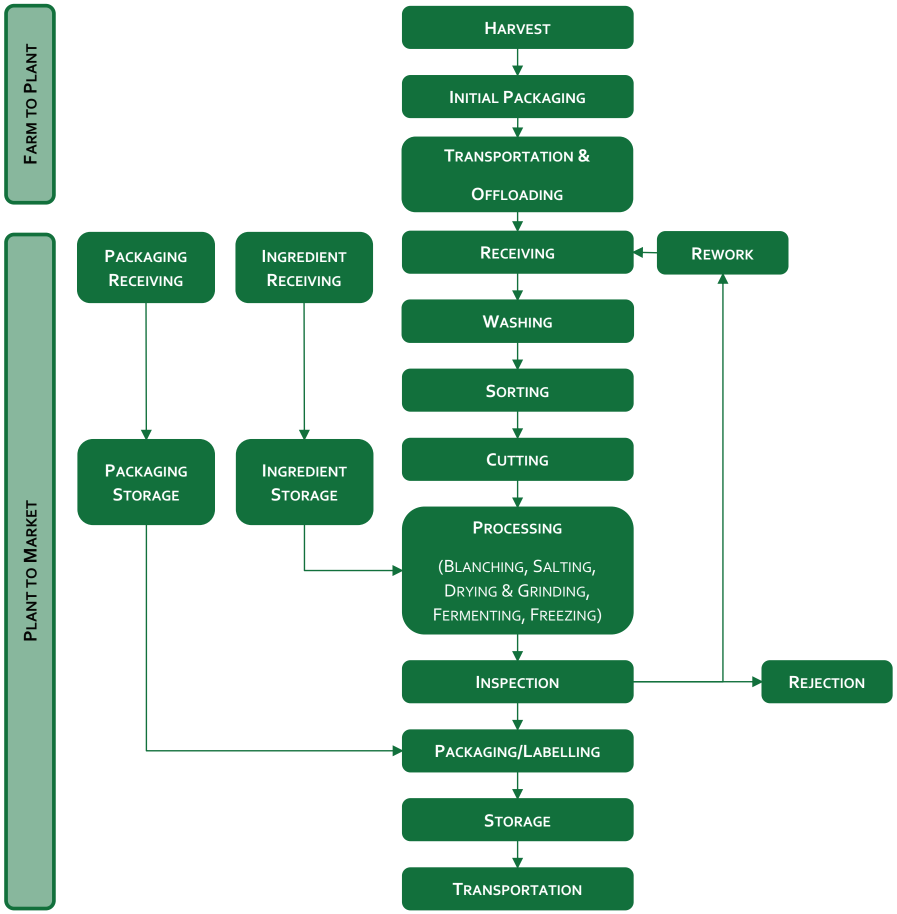

Figure 2. Decision tree indicating regulatory requirements throughout commercial production and sale of kelp products.

4.0
FOOD SAFETY

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Food businesses in Canada have a responsibility to produce safe food products. They must develop, implement and verify that processes followed during food manufacturing are effective at ensuring the safety of the food. These preventive food safety controls are unique to the manufacturing facility, the product and the processes used during manufacturing, and are a requirement to receive a Safe Food for Canadians license (Section 3.0). Preventive controls help to prevent food safety hazards and reduce the likelihood of contaminated food entering the market. Preventive controls consist of measures used to control hazards associated with the environment in which the product is processed.

One required component of a preventive control plan (PCP) is the identification of hazards that present a risk of contamination of foods. This is completed by performing a Hazard Analysis. The General Principles of Food Hygiene (CAC, 2020) provides guidance on the application of Hazard Analysis Critical Control Point (HACCP), which is a science-based preventative approach to control significant hazards at risk of being present in a food. A HACCP Plan/PCP consists of measures used to control hazards throughout the entire processing chain (i.e., harvest to distribution). The successful application of HACCP requires the commitment and involvement of all personnel, including management, and the knowledge and/or training in its application for the specific food type.

A PCP/HACCP analysis describes the significant hazards at risk of contaminating a food. When a critical control point is identified, these prevent, eliminate or reduce those hazards to an acceptable level. Control measures must be validated to prove effectiveness. When implemented effectively, the PCP/HACCP plan ensures products are produced and handled in an environment that minimizes the presence of contaminants in the food.

A HACCP plan for raw unprocessed kelp was recently developed by Concepcion et al. (2020), and a summary of hazards affecting seaweed products was recently reviewed (FAO and WHO, 2022; Løvdal et al., 2021) and summarized below in Section 4.2.

For guidance on developing quality assurance and food safety management systems for seaweed processors, see Perennia's Quality and Food Safety Guide for Seafood Processors.

4.0 FOOD SAFETY

4.1 KELP PRODUCTS AND PROCESSING

Importantly, HACCP plans are product and process specific, meaning a unique plan must be developed for each product going to market. Common kelp products listed below each have unique compositions and are produced using distinct processing operations that could introduce unique quality and safety concerns.

- Raw (fresh/frozen)
- Blanched (whole/cut, fresh/frozen)
- Fermented (whole/cut, fresh/frozen)
- Dried (whole/cut)
- Salted (whole/cut, fresh/frozen)

The general processing steps in transforming raw kelp into food products are outlined in **Figure 3**. Please note that this diagram should only be used as a guide when developing your process flow diagram. A process flow diagram should reflect actual practices at your facility.

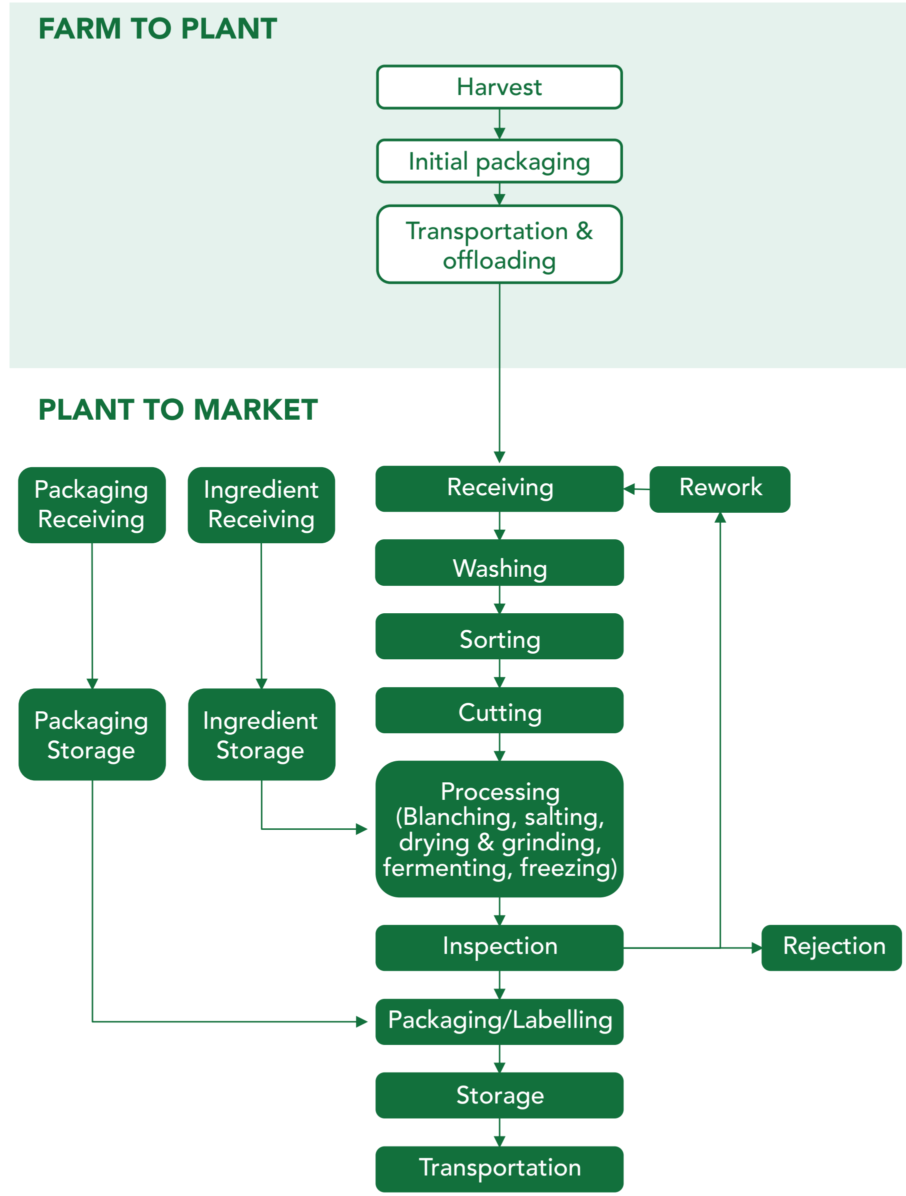


Figure 3. Example flow chart for different kelp product formats suited for food markets (Adapted from FAO and WHO, 2022). This chart does not include all elements that should be listed on a complete process flow diagram, such as processing outputs (waste, offal, compost) and non-food chemicals.

4.2 KELP HAZARDS

Successful implementation of HACCP requires complete identification of the potential hazards affecting kelp products. Food hazards are classified as either biological, chemical, or physical in nature. Hazards within each classification that could impact the safety of products produced from cultivated seaweed are highlighted below (**Table 3**). Some hazards will require samples to be sent to an accredited lab to verify their presence and quantity in kelp. A list of accredited labs can be found in **Appendix A**.

Table 3. Hazards associated with cultivated kelp products.

Hazard Classification	Seaweed-specific Hazard
Biological	• Dinoflagellate Toxins • Pathogenic Bacteria • Viruses • Yeast and Moulds
Chemical	• Allergens • Heavy Metals • Iodine • Marine Biotoxins • Persistent Organic Pollutants • Pesticides • Petroleum • Pharmaceuticals • Radionuclides
Physical	• Foreign Materials (metal, glass, hard plastics, wood, sand, shells)

Importantly, not all hazards listed in **Table 3** are directly relevant to all kelp product forms and storage conditions. Hazards for different food products are influenced by the unique biology of different seaweed species, the seaweed cultivation area and the post-harvest processes applied to prepare products for market.

4.2.1 KELP BIOLOGY-SPECIFIC HAZARDS

COMPOSITION

Chemical Hazards: Iodine

Consistent with the nutrient composition, chemical hazards can vary between different kelp species, seasonally, by age and in different components of the frond.

Kelp naturally contains high amounts of iodine, though there are differences between kelp species, in seaweeds grown in different geographic regions, in different parts of the thallus (Kreissig et al., 2021) and seasonally (Schiener et al., 2015).

Cultivation strategy can influence iodine accumulation. *S. latissima* grown in deeper water measure higher iodine contents than if grown closer to the surface (Blikra et al., 2021).

AGE

Chemical Hazards: Heavy Metals, Persistent Organic Pollutants, Radionuclides

Kelp can bioaccumulate environmental contaminants (heavy metals, persistent organic pollutants, radionuclides), and therefore older kelp with greater exposure time to these hazards presents a heightened risk to these chemical hazards. Differences in bioaccumulation rates between species have been identified, as well as an unequal distribution throughout the frond (Kreissig et al., 2021).

The heavy metals arsenic, cadmium, lead and mercury pose a moderate to high risk for bioaccumulation in seaweeds. Some seaweed contains high levels of aluminum (FAO and WHO, 2022). Persistent organic pollutants such as dioxins and polychlorinated biphenyls (PCBs), radionuclides from nuclear events, or petroleum residues such as polychlorinated aromatic hydrocarbons are considered low risk for contamination of seaweed.

HABITAT

Physical Hazards: Foreign Material (e.g., crustacean or mollusc shell)
Chemical Hazards: Allergens

Kelp beds provide a natural habitat for other marine species, including fish, shellfish and invertebrate species. Marine organisms that shelter in kelp beds can inadvertently be harvested and transported with the kelp into the processing plant.

Importantly, fish, crustaceans and molluscs are considered priority food allergens in Canada.

4.2.2 CULTIVATION AREA-SPECIFIC HAZARDS

Kelp can be at risk of acquiring biological and chemical hazards originating from their cultivation area. The cultivation site will influence the type of hazards kelp is exposed to. These hazards may be generated by anthropogenic activities or are naturally occurring.

ANTHROPOGENIC SOURCES

Industrial activities such as chemical plants, factories, power stations, water treatment facilities, or farms, and proximity to residential areas can be sources of biological and chemical hazards that can transfer to kelp cultivation sites posing a risk to the quality and safety of cultivated kelp.

Chemical Hazards: Heavy Metals, Persistent Organic Pollutants, Radionuclides, Petroleum

Industrial activity can potentially increase exposure to chemical hazards such as heavy metals. There is no standard for the limits of heavy metal found in seaweed in Canada, but this should not preclude the need for monitoring for these chemical hazards in the cultivation area. Bioaccumulation of heavy metals in brown seaweed occurs more rapidly than in either green or red seaweed.

Industrial activity may be sources of other environmental contaminants such as persistent organic pollutants, radionuclides from nuclear events, petroleum residues such as polychlorinated aromatic hydrocarbons, or fuel leaks from vessels on the farm site.

Biological Hazards: Pathogenic Bacteria
Chemical Hazards: Pesticides, Pharmaceutical residues

Farming (land-based or aquaculture) or proximity to residential areas may affect the bacterial quality of the cultivation area, increasing the risk of exposure to bacterial coliforms or bacterial pathogens such as *Salmonella* spp., *Escherichia coli* (*E. coli*), *Bacillus cereus* (*B. cereus*), *Listeria monocytogenes* (*L. mono*), or norovirus from agricultural, soil, or sewage runoffs. These hazards pose the greatest risk when kelp is intended to be marketed or consumed as a raw product. Farm runoff may also contain pesticide residues or pharmaceutical agents that can accumulate around the kelp cultivation site.

NATURALLY OCCURRING SOURCES

Natural events can lead to chemical and biological contamination of water surrounding kelp cultivation sites.

Biological Hazards: Pathogenic Bacteria (*Vibrio spp.*), Dinoflagellates

Multiple species of the genus *Vibrio* can cause foodborne illness, including *V. cholera*, *V. parahaemolyticus* and *V. vulnificus*. In summer, when water temperatures increase above 15 °C, *Vibrio spp.* are found more persistently in marine environments. *Vibrio parahaemolyticus* is a highly pathogenic bacteria and one of the primary causes of illness stemming from the consumption of raw or lightly cooked shellfish and may pose a similar risk for raw unprocessed kelp.

Chemical Hazards: Marine Biotoxins

Some microscopic marine algae can produce toxic compounds referred to as marine biotoxins under certain oceanic conditions. In the food system, marine biotoxins are directly associated with shellfish that can accumulate these toxins during filter feeding, but there is some evidence suggesting these toxin-producing algae can become physically associated with kelp blades. Biotoxins of interest include palytoxin, domoic acid and its analogues, ciguatoxins and cyclic imines (FAO and WHO, 2022).

The management and surveillance of toxic marine algae in marine waters is jointly managed by Environment and Climate Change Canada (ECCC), Fisheries and Oceans Canada (DFO) and the Canadian Food Inspection Agency (CFIA) as part of the Canadian Shellfish Sanitation Program (CSSP) (CFIA, 2022). Environment and Climate Change Canada is responsible for monitoring bacteriological water quality in shellfish harvest areas, identifying and evaluating sanitary pollution sources and recommending the classification assigned to shellfish harvest sites. Fisheries and Oceans Canada is responsible for the enforcement of closure regulations and enacting the opening and closing of shellfish harvest areas. The Canadian Food Inspection Agency is responsible for the control of handling and processing of shellfish, the marine biotoxin control program and liaising with foreign governments on matters relevant to shellfish sanitation.

4.2.3 PROCESS-SPECIFIC HAZARDS

A range of processing steps may be adopted when handling and transforming raw kelp into different food products. Although some processes are intended to deliberately control certain hazards, others can also introduce new hazards. Aspects of kelp processing where hazards can be introduced to kelp products are detailed below, including a description of those hazards.

Visit the CFIA's Reference Database for Hazard Identification or the Food and Drug Administration's Fish and Fishery Products Hazards and Control Guidance for a comprehensive list of food safety hazards associated with processes used during the processing and handling of marine products.

HYGIENE

Good hygiene practices apply to harvest practices on the farm, the processing establishment, the personnel operating on the farm and within the processing establishment and the practices taking place within the facility.

Biological Hazards: Pathogenic Bacteria (*Salmonella spp., E. coli, S. aureus, L. monocytogenes*), Viruses (norovirus)

Pathogenic bacteria may be transmitted directly or indirectly onto seaweed by food handlers, through contact with surfaces, from cleaning equipment, by splashing, or by airborne particles. Bacterial pathogens *Salmonella spp.*, *E. coli*, *Staphylococcus aureus* (*S. aureus*) and norovirus are commonly transmitted through bodily fluids. Personnel who encounter kelp should maintain a high degree of personal hygiene, wear suitable protective clothing, hair and beard nets, and should regularly wash their hands, even if wearing gloves. Personnel should avoid spitting, eating, drinking, touching the mouth or nose and coughing or sneezing around unprotected kelp.

Listeria monocytogenes is a bacterial pathogen commonly transmitted from the food processing environment onto food products. Proper sanitation practices ensure that food-contact surfaces and equipment are adequately cleaned and prevented from becoming vectors of transmission of pathogenic bacteria.

Chemical Hazards: Non-food Chemicals (e.g., sanitation, cleaning, lubricants, oil), Allergens

Surfaces, utensils, equipment and tools that may come in direct contact with kelp should be free of chemical residues, such as sanitizer, lubricants, or oil.

Personnel who come into direct contact with kelp should follow proper handwashing procedures to prevent cross-contact of allergens to the product. Allergens can also be transferred by equipment or other food-contact materials that were not adequately cleaned or segregated during storage.

Physical Hazards: Foreign Material (e.g., jewelry)

Personnel who come into direct contact with kelp throughout its transformation should not wear jewelry as it can become a physical hazard.

INITIAL PACKAGING

Biological Hazards: Pathogenic Bacteria

Proper drainage of containers and time/temperature monitoring should be adopted to prevent temperature abuses during harvest that could promote the growth of pathogenic bacteria in the product or within the container itself.

Chemical Hazards: Non-food Chemicals, Allergens
Physical Hazards: Foreign Material (e.g., metal pieces, glass, plastic)

When storing kelp during harvest, containers should be clean and not become a source of contamination of any hazard type. If using fish boxes that were previously used to store fish or shellfish, they should be properly cleaned before being used for kelp. Inadequate cleaning may pose a contamination risk of fish and shellfish allergens, non-food chemicals, physical objects and pathogenic bacteria to kelp supplied to the processing facility.

STORAGE (Ambient, Chilled and Frozen)

Biological Hazards: Pathogenic Bacteria

Time/temperature abuses can enable the growth of pathogenic bacteria and product contamination. Chilling is an effective control to prevent the growth of microorganisms. An emphasis should be placed on reducing the bulk temperature of harvested kelp immediately post-harvest to control the growth of bacteria from the harvest area associated with kelp fronds.

Keeping kelp cool is necessary throughout the supply chain to ensure that any potential contamination with pathogenic bacteria or their spores is prevented from growing and to slow the growth of other microbes that reduce the overall quality and shelf-life of fresh kelp. The minimum temperature for the growth of different biological hazards is represented below (Løvdal et al., 2021).

- *E. coli* = 6.5 °C
- *Salmonella* spp. = 5.2 °C
- *Staphylococcus aureus* = 7 °C
- *Clostridium botulinum* type E (non-proteolytic) = 3.3 °C
- *Clostridium botulinum* type A, B (proteolytic) = 10 °C
- *Vibrio parahaemolyticus* = 5 °C
- *Listeria monocytogenes* = -0.4 °C
- *B. cereus* = 4 °C

Chilling alone is not sufficient to provide complete protection from microbial growth. Freezing to -18 °C will effectively stop all microbial activity, but it is not effective at killing them. When thawed, these biological hazards will still be present and must be adequately controlled.

Inadequate control of ambient environments where packaging is stored could lead to packaging damage and the opportunity for growth of yeast and moulds.

Chemical Hazards: Non-food Chemicals (e.g., coolant, lubricant)
Physical Hazards: Foreign Material

TRANSPORTATION & OFFLOADING

Biological Hazards: Pathogenic Bacteria

Time/temperature abuses during vessel off-loading and ground transportation can increase the risk of contamination by pathogenic bacteria.

Inadequate protection from the environment may expose raw kelp to birds or other animals during offloading, and to condensate drips in refrigerated trucks that also increase risk of contamination by pathogenic bacteria.

Chemical Hazards: Non-food Chemicals, Allergens
Physical Hazards: Foreign Material (e.g., metal pieces, glass, plastic)

Good hygiene practices should be followed to prevent contamination of kelp by personnel, equipment or materials that make direct food contact.

RECEIVING

Biological Hazards: Pathogenic Bacteria
Chemical Hazards: Non-food Chemicals, Allergens
Physical Hazards: Foreign Material (e.g., metal pieces, glass, plastic)

When receiving kelp into the plant, good hygiene practices should be followed during initial inspections and sampling to prevent contaminating the raw kelp.

WASHING

Biological Hazards: Pathogenic Bacteria
Chemical Hazards: Non-food Chemicals

Washing raw kelp should be performed to remove any organic or inorganic materials found on the frond. Scrubbing debris off the kelp blade's surface is ineffective at eliminating biological or chemical hazards. Any non-food chemicals used during washing should be adequately rinsed from the product.

Water used for washing must be potable and meet Health Canada's Guidelines for Canadian Drinking Water Quality.

Physical Hazards: Foreign Material

Inadequate washing may allow physical objects that can cause adverse health effects to remain associated with the raw kelp.

SORTING/INSPECTING

Biological Hazards: Pathogenic Bacteria
Chemical Hazards: Non-food Chemicals
Physical Hazards: Foreign Material

Good hygiene practices should be followed to prevent contamination of kelp by personnel, equipment or materials that make direct food contact.

CUTTING (e.g., slicing, dicing, mincing, chopping, flaking, shredding)

Biological Hazards: Pathogenic Bacteria
Chemical Hazards: Non-food Chemicals, Allergens
Physical Hazards: Foreign Material

Cutting techniques may be adopted to transform the raw kelp into different product formats suited for end-use applications. Both manual and automated processes rely on metal blades, which presents a risk of breaking, chipping, or generating metal shavings that could contaminate finished products with metal fragments. Metal detection on the finished product may be necessary to control the risk of metal fragments entering the food supply chain.

BLANCHING

Biological Hazards: Pathogenic Bacteria
Chemical Hazards: Non-food Chemicals

Good hygiene practices should be followed to prevent contamination of kelp by equipment that makes direct food contact.

FERMENTING

Biological Hazards: Pathogenic Bacteria

Fermentations rely on starter cultures for inoculating raw kelp with microbes that compete with and prevail over potentially pathogenic bacteria that could be present. Starter cultures are susceptible to failure, which would allow potentially pathogenic bacteria to contaminate these cultures. Starter cultures and kelp fermentations are both susceptible to contamination by personnel and food-contact equipment. Improper pH adjustments or insufficient fermentation leading to insufficient pH reduction could also expose kelp products to potentially pathogenic bacteria.

DRYING

Fresh kelp has a water activity ranging from 0.97 to 0.99, making it an ideal environment for bacterial growth (Wirenfeldt et al., 2022).

Biological Hazards: Pathogenic Bacteria, Yeast & Moulds

Modifying the water activity of kelp by drying can protect it against different biological hazards. The minimum water activity for the survival of various biological hazards is represented below (Fontana Jr, 2007):

- *E. coli* = 0.95
- *Salmonella* spp. = 0.95
- *Staphylococcus aureus* = 0.85
- *Clostridium botulinum* type E (non-proteolytic) = 0.97
- *Clostridium botulinum* type A, B (proteolytic) = 0.94
- *Vibrio parahaemolyticus* = 0.94
- *Listeria monocytogenes* = 0.92
- *B. cereus* = 0.93
- Yeast = 0.62
- Moulds = 0.6

Maintaining the water activity of dried seaweed products below 0.6 is effective at protecting against the growth of biological hazards.

Chemical Hazards: Non-food Chemicals
Physical Hazards: Foreign Material

GRINDING

Biological Hazards: Pathogenic Bacteria

The build-up or accumulation of kelp in equipment during processing for extended periods can lead to time/temperature abuses that support the growth of pathogenic bacteria.

Chemical Hazards: Non-food Chemicals
Physical Hazards: Foreign Material

4.0 FOOD SAFETY

SALTING

Biological Hazards: Pathogenic Bacteria

The addition of salt is another control against biological hazards. The salt content of a food influences the ability for bacteria to survive in that environment. Modifying the water phase salt (WPS) of foods can protect them against different biological hazards. The maximum WPS (%) that biological hazards can grow is represented below (Løvdal et al., 2021):

- *E. coli* = 6.5%
- *Salmonella* spp. = 8%
- *Staphylococcus aureus* = 20%
- *Clostridium botulinum* type E (non-proteolytic) = 5%
- *Clostridium botulinum* type A, B (proteolytic) = 10%
- *Vibrio parahaemolyticus* = 8%
- *Listeria monocytogenes* = 10%
- *B. cereus* = 10%

Calculation: Water Phase Salt (%)

$$\textbf{Water Phase Salt} = \frac{\text{Salt (\%)}}{\text{Moisture (\%)} + \text{Salt (\%)}} \textbf{ x 100}$$

PACKAGING

Packaging serves multiple purposes. It functions as a physical barrier from the external environment and protects products inside from further contamination by physical and chemical hazards.

Biological Hazards: Pathogenic Bacteria

Biological hazards associated with packaging may be derived from the packaging process and the environment created by the packaging. Packaging functions as a physical barrier but still enables gas transmission between the external and internal environment. Vacuum packaging, the use of packing films with low oxygen transmission rates, glass jars or cans are examples of Reduced Oxygen Packaging. When oxygen is restricted, some pathogenic bacteria, such as *Clostridium botulinum*, are not prevented from forming toxins and would represent a significant health hazard unless other control measures are adopted, such as refrigeration, salting, or drying.

Packaging materials should be stored in a clean and dry location to prevent them from becoming physically damaged or contaminated by biological or chemical hazards found throughout the processing facility.

Chemical Hazards: Non-food Chemicals
Physical Hazards: Foreign Material

LABELLING

Labelling refers to information represented on the product packaging, including lot coding, which is an important aspect of managing product traceability.

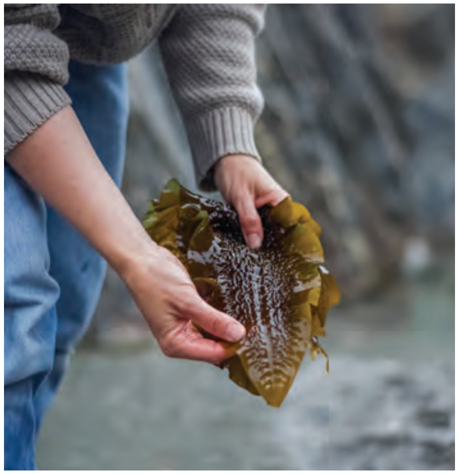
Biological Hazards: Pathogenic Bacteria

Indicating accurate storage requirements for the control of potentially pathogenic bacteria is critical. Inaccurate date-marking could allow products unsafe for consumption to remain in the market or prevent their accurate traceability. Damage that occurs when label or date codes are applied to packaging could expose the product to potentially pathogenic bacteria.

Chemical Hazards: Non-food Chemicals, Inks/Solvents, Nutritional Data, Allergens

Inks and solvents involved in the labelling application could contaminate products. Using an incorrect label could result in a product containing undeclared allergens or the portrayal of inaccurate nutritional information.

Physical Hazards: Foreign Material



5.0 MANUFACTURING OF KELP-BASED FOOD PRODUCTS

5.0 MANUFACTURING OF KELP-BASED FOODS PRODUCTS

5.1 QUALITY ATTRIBUTES OF KELP

There are no global standards for the safety and quality of kelp products, but customers still require a consistent product of high quality. Producers may develop their own internal grading system or may be required to meet customer specifications. It is, therefore, important to understand the interaction between handling and processing practices and the consequence on kelp quality and shelf-life. The following characteristics, or a combination thereof, may be adopted to represent the quality attributes of kelp:

- Size, colour, appearance
- Sensory characteristics (texture, odour, flavour)
- Microbiological contents
- Respiration rate
- Nutrient content (moisture, carbohydrate, protein, fat, vitamin, mineral, polyphenol)
- Functionality (antioxidant activity, gelling activity)

Table 4. Quality grades of fresh kelp (*Laminaria japonica*) cultivated in China (Adapted from Scoggan et al., 1989).

Specifications				
Grade	**Frond Length (cm)**	**Blade Dimension**	**Colour**	**Water Content (%)**
Class 1	> 100	Length: >70 cm Width: >12.5 cm Integrity: unbroken	Dark brown in colour, no yellowing on edges or tips of the flat blade portion. Yellowing < 25% on surfaces excluding flat blade portion	< 22
Class 2	> 80	Length: >50 cm Width: >9 cm Integrity: broken blades permitted	Dark brown in colour, no yellowing on edges or tips of the flat blade portion. Yellowing < 50% on surfaces excluding flat blade portion.	< 22
Class 3	> 60	Length: >40 cm Width: >6 cm Integrity: broken blades permitted	Dark brown or yellow-brown in colour	< 22

5.2 CONSIDERATIONS DURING KELP HARVESTING

The overall goal of harvest is to recover a quantity of raw kelp biomass from the farm and to transfer the kelp to the processing plant in a manner that preserves the quality and likeness of the photosynthesizing plant. The following sections describe important considerations around kelp harvesting.

HARVEST TIMING

Potential Hazards: Biological, Physical
Potential Defects: Low yield, Nutrient deficiencies

Depending on the size of the farm, harvest can take days to weeks. Careful planning around when to begin harvesting should take place to ensure no adverse change in the characteristics, nutritional composition, and functionality desired for the finished product takes place over this period.

A main determinant of deciding when to begin harvesting is when recoverable biomass is at a maximum. A reliable indicator to begin harvest is the thickness of kelp blades. Blades stop growing in length once they mature but continue to thicken and add to overall recoverable biomass. Thickness provides an indication of the fresh weight to dry weight ratio, an important criterion for assessing when maximum biomass recovery of dried kelp is attained. As blade thickness increases, this ratio decreases (more solids, less moisture). Blade thickness should be measured in the dried form, and a ratio of 6.5:1, fresh weight to dry weight, is considered optimal. Blade thickening occurs faster at higher seawater temperatures, so seawater temperatures can also be used to indicate when to harvest. Blade thickening occurs at rates proportional to depth, as plants that receive more sunlight thicken faster than those at lower depths where light is more restricted. A staggered harvest could provide an opportunity for more thickening to occur if kelp at shallower depth is harvested first.

As the fresh weight to dry weight ratio continues to decrease < 6.5:1, rising water temperatures eventually leads to deterioration and loss of overall biomass. Additionally, increasing temperatures result in an added microbial load on seaweed blades, as well as an increased presence of marine invertebrates (e.g., bryozoans). Optimal harvest timing is ultimately site-specific, but there are consequences to being both too early and too late.

HYGIENE

Potential Hazards: Biological, Chemical, Physical
Potential Defects: Spoilage

Following good hygiene practices will prevent contamination by bacteria from personnel, food contact surfaces and equipment to the product. These bacteria may contribute to foodborne illness or accelerate spoilage processes that reduce the overall quality. Tools, equipment and other materials used in the harvesting of kelp should be properly cleaned and sanitized prior to their use. This includes harvesting equipment, fish boxes, knives, the deck of vessels, or any other surface that makes direct contact with any part of the kelp.

INITIAL PACKAGING OF RAW AQUACULTURE COMMODITY

Potential Hazards: Biological, Chemical, Physical
Potential Defects: Physical damage, Spoilage, Appearance

The strategy for the initial packaging of harvested kelp can influence the quality and shelf-life of the product. The optimal selection of a container or containment solution for storing seaweed during harvest should consider several factors.

Some examples of storage containers used during kelp harvesting include fish boxes, produce bins, plastic drums, baler bags, or the deck of vessels. However, there are advantages and disadvantages to each during harvest regarding the optimal condition for the kelp, convenience during harvesting and risks for introducing potential hazards.

Containers used during harvest should enable chilling to take place immediately. Chilling can occur ambiently in cool air, using bagged ice, ice packs, seawater, or even recirculating seawater systems. Although conventional fish boxes can store large quantities, they make quick chilling throughout the harvested biomass difficult and increase susceptibility to temperature abuses.

Large quantities packed together may also restrict access to oxygen needed by kelp for respiration. Storage should provide good airflow to access oxygen throughout the harvested kelp biomass. When oxygen is restricted, conditions ideal for active fermentation are established. Furthermore, packaging large quantities of kelp together may cause crushing, broken blades, and/or damage to plant tissues that can accelerate rot, quality loss and a reduced shelf-life.

Initial packaging should permit drainage to prevent kelp from pooling in standing water.

CHILLING

Potential Hazards: Biological, Chemical, Physical
Potential Defects: Spoilage

Harvesting can take many hours to collect sufficient biomass for the processing plant. Chilling freshly harvested kelp should be adopted to control the growth of bacteria found naturally on kelp blades or introduced by workers during handling. Inadequate chilling combined with extended storage periods will accelerate the deterioration of kelp and shorten its shelf-life. The use of ice in direct contact with kelp should be avoided to prevent the localized freezing and damage to kelp blades, as well as the association of kelp with freshwater.

PRODUCT EXPOSURE

Potential Hazards: Biological, Chemical, Physical
Potential Defects: Dehydration, Appearance

Freshly harvested kelp should be protected from environmental exposure.

Dry air and direct sunlight may promote the dehydration of kelp blades. Physical changes to blades may make these parts unsuitable for the finished products and lower overall yields.

Kelp should be covered to provide protection from wildlife.

Harvesting kelp should be avoided when it is raining unless it can be adequately protected. The interaction of freshwater with kelp should be kept to an absolute minimum, as freshwater may cause leaching of nutrients from the kelp and physical changes such as blistering on kelp blades.

STORAGE TIME

Potential Hazards: Biological, Chemical
Potential Defects: Spoilage, Sensory (flavour, odour), Appearance

Harvested kelp requires a cool, moist and well-oxygenated environment while actively respiring. Kelp ceases to respire after 4 to 5 days and has an overall shelf-life of 7 to 9 days.

Harvesting should take place only when processing capacity is available so that the time kelp must be stored prior to processing is kept to an absolute minimum.

In the raw state, naturally occurring bacteria on the surface of kelp blades remain active, even under chilled storage and contribute to the overall deterioration of the kelp. Ideally, seaweed should be processed within 24 hours of harvest.

TRANSPORTATION & OFFLOADING

Potential Hazards: Biological, Chemical, Physical
Potential Defects: Spoilage

Transportation of kelp from the farm to the processing establishment and its offloading from vessels at the wharf and from trucks into the processing establishment should maintain kelp quality and safety.

Refrigerated transport may be necessary to maintain the appropriate storage condition for the product to prevent the growth of pathogenic bacteria. Trucks should be inspected prior to loading to ensure they are clean and free from potentially contaminating hazards. When offloading, product should be conveyed immediately into an appropriate storage area. If storage areas are unavailable, product should remain on the truck until spaces become available.

Protection from environmental exposure continues to be important during transport and offloading. Environmental conditions may differ between the harvest area, where offloading takes place and where the processing establishment is located. What may be adequate at the time of harvest may not be sufficient to protect kelp the following day or at another location.

5.3 CONSIDERATIONS DURING KELP PROCESSING

Once transferred from the farm to the processor, the next objective is to transform the raw aquaculture commodity into finished products that can be marketed and sold. Processing activities include maintaining appropriate documentation, physically transforming the kelp, packaging, labelling and storage. Best practices in steps involved with processing kelp are outlined below.

RECEIVING

Potential Hazards: Biological, Chemical, Physical
Potential Defects: Spoilage, Appearance, Sensory (flavour, odour, texture)

Receiving procedures at the processing plant involve weighing and inspecting a lot of the raw aquaculture commodity.

Inspections should note the temperature upon receiving the product to verify that chilling has been performed effectively.

The overall condition of the kelp should be evaluated to verify that it is acceptable for further processing.

WASHING

Potential Hazards: Biological, Chemical, Physical
Potential Defects: Appearance

Washing kelp should be completed to remove any foreign material physically associated with the blades or captured within harvested biomass.

Washing may be completed by soaking or physically disturbing any biofouling or soil on the surface of the blades. Major biofouling organisms include bryozoans, hydroids, tube-building amphipods, tunicates and other debris, including microorganisms (Visch, 2020).

Washing of containers or packaging materials should be performed to prevent contamination of products. Containers may contain residues of foreign material or chemical cleaners and harbour pathogenic bacteria if not adequately cleaned.

SORTING

Potential Hazards: Biological, Chemical, Physical
Potential Defects: Appearance, Sensory (flavour, odour, texture)

After washing, sorting kelp by quality characteristics or size may be performed to improve the down-stream handling and for marketing distinct products. For instance, larger kelp blades also grow thicker and may be better suited for kelp noodle, salad, or pickling applications. Alternatively, different blanching schedules may be optimized for the largest versus the smallest size kelp blades.

Rough handling, crushing under excess weight and excessive vibration during harvest, transportation and washing practices may cause tears or broken blades, making those products poorly suited for different end-use applications.

CUTTING (e.g., slicing, dicing, mincing, chopping, flaking, shredding)

Potential Hazards: Biological, Chemical, Physical
Potential Defects: Miscuts

Cutting may be performed to reduce large kelp fronds into portions better suited for processing and various end-use applications, such as kelp noodles, or use in soups, salads, or pickling.

Pre-packaged food products for retail sale, such as dried kelp blades, must be packaged to a consistent net weight, and cutting to consistent sizes ensures this is achieved. Sorting prior to cutting will help ensure the consistency of the product.

BLANCHING

Potential Hazards: Biological, Chemical
Potential Defects: Discolouration, Sensory (flavour, odour, texture)

Blanching is a heat treatment performed to inactive food enzymes and/or to fix the colour of a product (CAC, 2008). Blanching will change the appearance of fresh kelp from a golden brown colour to vivid green to make it more appealing for different applications.

Important aspects of the blanching process include the blanching method, the blanching temperature, the blanching time and post-blanch chilling.

Blanching methods rely on moist heat, where kelp fronds or pieces may be immersed directly into hot water or steam or packaged first and then heated. Temperatures ranging from 30 to 100 °C and blanching times from 2 sec to 3 min have been used with success to achieve desired product changes.

Blanching inhibits the ability for kelp to respire and can lead to a reduction of certain nutrient contents (Wirenfeldt et al., 2022). For instance, blanching significantly reduced the iodine content of raw sugar kelp after a two second immersion in 45 °C water. However, the content of ash, amino acids, fatty acids and antioxidant activity also reduce after blanching (Nielsen, 2020). Blanching can drive water uptake or loss depending on whether freshwater or seawater is used and how subsequent cooling steps are performed. Kelp will soften when blanched, with longer blanching times leading to greater softening. Consumer sensory evaluations have shown that blanching improves both flavour and overall liking of sugar kelp compared to the raw product (Akomea-Frempong, 2021; Wirenfeldt et al., 2022).

SALTING

Potential Hazards: Biological, Chemical, Physical
Potential Defects: Appearance, Sensory (flavour, odour, texture)

Salting is a preservation method that extends the shelf-life of foods. Salt draws moisture out of products aiding their dehydration and modifies the product's salt content. Both changes help to control microbial growth and can extend the shelf-life of fresh kelp to 90 days (Perry et al., 2019).

High salt treatments (200 g salt/kg kelp) are more effective at removing water than low salt treatments (50 g salt/kg kelp). A high salt treatment can reduce the water activity of fresh kelp from 0.99 to 0.84, compared to a low salt treatment that reduced water activity from 0.99 to 0.96 after only 24 hours (Perry et al., 2019). Compared to a low salt treatment, kelp treated with high salt produced a more favourable product in terms of colour, odour and texture.

Continuous refrigeration is needed to preserve the appearance and texture of fresh salted kelp over a 30-day period, except at the highest salt concentrations (30%), where ambient storage was adequate (Wei, 2021).

DRYING

Potential Hazards: Biological, Chemical, Physical
Potential Defects: Appearance, Sensory (texture), Loss of function

Drying processes assist in dehydrating products. The main purpose of dehydration is to preserve products by reducing their water activity. Drying occurs when moisture within a food evaporates into the air, and the speed of evaporation from a food is affected by the humidity of the air, the air temperature and the amount of air that passes over the food. Low humidity air, at high temperatures and moving at high speed over a maximal product surface area will maximize the drying speed.

Heat to promote drying may be provided by solar radiation (sun-drying), combustion (smoking), or by electricity (mechanical heat generation), and sources of airflow include wind or electric fans or a combination. A combination of drying temperatures may be adopted to establish the optimal balance between quality and safety.

Kelp should be dried to a water activity < 0.85 to ensure pathogenic bacteria cannot grow, to < 0.6 to ensure yeasts or moulds cannot grow, and ideally even lower to minimize oxidation impacting the overall appearance.

Freeze drying is the process of converting ice into water vapour through sublimation. It is performed under vacuum at ~ -40 °C, so the presence of heat and oxygen during the drying process are limited. Even still, colour changes and lipid oxidation during storage of freeze dried seaweed occur faster than if oven-dried (Harrysson et al., 2021). Freeze dried kelp products have been prepared with good success, but the cost of production is far higher than traditional or other mechanical air-drying processes.

Oxidation is a mechanism of deterioration that impacts the appearance and functional benefit of kelp products. Oxidation requires oxygen and is accelerated by high temperatures and light exposure. Drying at higher temperatures can reduce the total phenolic content and the antioxidant activity of dried sugar kelp (Sappati, 2020).

GRINDING

Potential Hazards: Biological, Chemical, Physical
Potential Defects: Clumping, Oxidation, Appearance, Sensory (flavour, odour)

Dried kelp can be milled or ground into flour or flakes for use in seasonings, baked goods, or as a component of other food products.

During the grinding process, metal fragments, wood and insects associated with seaweed or grinding equipment may end up in the milled product and represent a reasonable risk to human health.

Flours and flakes are commonly represented using a mesh size, a measurement indicating the particle size dimension where 98% of a granular product can pass through a standardized sieve. The mesh size of milled kelp can dictate its suitability for different applications. There can be an unequal nutritional composition in different particle size fractions of milled kelp.

FREEZING

Potential Hazards: Biological, Physical, Chemical
Potential Defects: Texture, Appearance, Drip-Loss, Dehydration

Freezing is a preservation method involving the physical transformation of moisture within seaweed from liquid water to solid ice. Freezing of raw kelp may be completed to stabilize it for processing at a later date or to extend the shelf-life of finished products. Freezing may be performed on the raw kelp, before or after blanching, as a whole or trimmed product, and with or without packaging.

Important considerations for freezing include the product format, freezing method, freezing time and at what stage during processing to freeze.

The selection of the optimal freezing method will depend on the product format to be frozen. Although individual fronds may freeze quickly due to the exposure of a maximum surface area, it will be difficult to handle and store after freezing. Additionally, freezing exposed fronds could make them susceptible to dehydration during the freezing process.

Freezing methods such as air blast freezing, plate freezing, or immersion freezing can be effective if products are adequately protected from the freezing medium.

Unlike drying methods that employ elevated temperatures and can lead to nutrient losses, the act of the freezing process does not directly cause nutrient loss. Rather, all frozen kelp must be thawed prior to further processing or consumption, and freeze/thaw cycles can drive moisture losses, or drip-loss, due to structural changes within kelp that prevent it from holding onto that water. These losses can amount to up to 25% of wet weight, and water-soluble chemical constituents, such as carbohydrates or vitamins, may be lost from the product.

FERMENTATION

Potential Hazards: Biological, Chemical, Physical
Potential Defects: Sensory (flavour, odour, mouthfeel), Appearance

Fermentation can transform the taste, texture and other characteristics of kelp products to make them more suitable for different end applications.

Fermentation involves using microbial sources to modify the properties of kelp products. Bacteria, yeast, or moulds feed on carbohydrates available within kelp and cease activity when nutrients are no longer available. Consistent fermentation, therefore, is subject to the availability of nutrients within kelp that can vary between different harvest areas or at different times of the year.

Strategies to perform fermentation should be assessed to ensure processes generate consistent end products. Incomplete or unsuccessful fermentations may permit bacteria other than the intended cultures to thrive in the product leading to deterioration and development of undesirable characteristics.

PACKAGING

Potential Hazards: Biological, Chemical, Physical
Potential Defects: Dehydration, Sensory (texture)

Packaging functions as protection against environmental conditions and from contamination and simplifies handling by customers or consumers. The ideal packaging for kelp products will depend on the characteristics of the product (fresh, frozen, or dried).

Fresh kelp is actively respiring, and packaging should permit cooling, access to oxygen, as well as protection from recontamination.

Frozen kelp is vulnerable to dehydration if not adequately protected during freezing and cold storage.

Dried kelp is vulnerable to rehydration from atmospheric moisture and should be protected.

5.0 MANUFACTURING OF KELP-BASED FOODS PRODUCTS

STORAGE

Potential Hazards: Biological, Physical, Chemical
Potential Defects: Dehydration, Appearance, Sensory (flavour, odour, texture)

The quality attributes of kelp products may be impacted by the storage conditions where they are held. Conditions for storage may include ambient, refrigerated, or frozen (cold) storage to provide control over food pathogens. In all storage conditions, maintaining a consistent environment is critical to prevent accelerated deterioration and a reduced shelf-life.

Important aspects of storage of minimally processed seaweed products include temperature, access to oxygen, light exposure, the product format and storage time.

Reducing or eliminating oxygen helps to prevent oxidation of foods, but complete restriction of oxygen may require refrigerated storage of pre-packaged foods throughout the supply chain to control pathogenic bacteria.

Long-term (~ 1 year) frozen storage impacted colour and texture characteristics of sugar kelp, whereas short-term (24 hr) storage did not (Akomea-Frempong, 2022). These textural changes were directly related to the storage time.

Dried kelp should be stored in a low-humidity environment (< 60% relative humidity) to protect kelp from the growth of yeast or mould. Monitoring the water activity of dried kelp should be performed to ensure storage conditions remain adequate for protection against bacterial contamination. Additionally, products intended to be rehydrated should be evaluated periodically to ensure that quality in the rehydrated state is consistent over the storage period.

6.0 FOOD LABELLING

6.0 FOOD LABELLING

Food labelling regulations in Canada are outlined in *Safe Food for Canadian Regulations and Food and Drug Regulations*. See Perennia's Seafood Labelling fact sheet for specific details on the requirements for pre-packaged and consumer pre-packaged seafood products.

In general, information required to be found on food product labels:

- Common name of the product
- Net quantity
- Labelling for storage instructions and handling
- Nutrition facts, list of ingredients, and allergen labelling
- Name and principal place of business
- Country of origin
- Date markings (best before, package on, or expiration date)
- Lot code
- Bilingual requirements

CLAIMS

Food manufacturers may also voluntarily include other statements that help to describe and differentiate their products in relation to their method of production, environmental impact, composition, and/or quality. Any claims used on food labels must be accurate, truthful and must not mislead or deceive the consumer, meaning they must be substantiated using either third-party audit, valid documentation, or a non-governmental certification program.

Method of production claims found on food labels include claims of natural, kosher, halal and non-GMO.

Composition claims may include terms such as 100% pure, vegetarian/vegan, terms such as true, real, or genuine, highlighting trace ingredients, or using negative claims like dairy-free or no artificial sweeteners.

Nutrient content claims such as 'low in fat', 'source of omega-3 polyunsaturated fatty acids', 'high in protein', or 'no added sugar' are acceptable terms when foods meet the conditions outlined by the Canadian Food Inspection Agency.

Health claims such as disease risk reduction, therapeutic, or function claims imply that a relationship exists between the consumption of a food and health. Any health claims must be substantiated by scientific evidence and reviewed by Health Canada.

Environmental claims include claims of sustainability and organic production. Substantiating a claim of sustainability for cultivated kelp can be achieved by attaining Best Aquaculture Practices (Seaweed Farm Standard Issue 1.0 will be published in Q1 2023) or the Aquaculture Stewardship Council/Marine Stewardship Council certifications for seaweed farms. To make an organic claim on aquaculture products, including seaweed, practices must comply with the Organic Aquaculture Standard and be certified by an accredited certification body. When certified, products are permitted to bear the Canada Organic logo.

7.0 REFERENCES

7.0 REFERENCES

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APPENDIX A

ACCREDITED FOOD AND ENVIRONMENTAL TESTING LABS

NOVA WEST LABORATORY LTD.

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