

AFDF Joint Innovation Project Final Report

**Pilot Scale Forced-Air Drying and Milling of Farmed Kelp-
Gateway to Mid to Large Scale Drying, Qualitative Assessment,
and Development of Dried Kelp Products from *Saccharina latissima*
(sugar kelp), *Nereocystis luetkeana* (bull kelp) and *Eualaria fistulosa*
(dragon kelp)**

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Abstract

Kelp is a perishable crop that requires stabilization within 24 hours of harvest. Drying and milling of kelp eliminates weight and volume from moisture and converts the kelp into a product that can be easily stored and transported under ambient conditions. Kelps grown in Alaska differ from kelps currently grown and dried in other regions of the world, as either novel species or having a phenotype distinct from those currently grown and dried elsewhere. This study focused on three Alaskan kelp species: *Saccharina latissima* (sugar kelp), *Nereocystis luetkeana* (bull kelp), and *Eualaria fistulosa* (dragon kelp), cultivated in the Kodiak Archipelago. Their performance was evaluated in a pilot-scale forced-air cabinet drying system (70 °C for 8 hours, ≤45 kg wet kelp, ~3.67 kg dry kelp) and a pilot-scale mini hammermill (<150 kg/hour). Percent recovery of dried and milled kelp ranged from 6.268% - 13.498% recovery. Water activity levels of the dried kelps were adequate to suppress the growth of microorganisms ($w_a=0.377-0.202$). The production cost per dry kilogram was estimated to be \$40.23, most of which was due to labor costs (\$98.20 per load). The resultant nutrient, heavy metal, and microbiological status of the dried and milled kelps were also analyzed. The kelps had N-P-K ratios for fertilizer averaging 1-2-18. Microbial testing indicated that the procedures used were sufficient to prevent the introduction of pathogenic bacteria but some non-speciated, non-pathogenic bacteria, yeast, and mold did survive the drying process or were possibly introduced post-drying during milling and packaging. The kelps were high in the heavy metals arsenic (58.2-86 µg/g) and cadmium (0.48-4.92 µg/g) and also had high iodine levels (338-3,940 µg/g), all concerns for the establishment of a daily serving size and product labeling requirements on federal and state levels. Overall, further research is needed to optimize drying systems for these three kelp species, address concerns about heavy metal and iodine content, and reduce the high cost of production.

Keywords: *ambient stabilization, bull kelp, dragon kelp, forced air drying, Eualaria fistulosa, milling, Nereocystis luetkeana, primary processing, Saccharina latissima, sugar kelp*

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Chronology

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Introduction

Kelp is highly perishable and must be stabilized within 48 hours of harvest, typically through methods like freezing, blanching and salting, acidification, or drying (Perry et. al., 2019). These are considered primary preservation techniques used to prepare kelp for transport to processing and refinement facilities or inclusion in other products. However, because kelp is 93–98% water, and some methods require the addition of more water, transporting it is costly, especially when further refinement is needed (Gallagher et. al., 2017). This presents a major challenge for Alaskan kelp farmers, who are often located far from processing infrastructure.

Drying is a method of preservation that allows for a reduction in water weight related shipping costs and is seen as a further refinement of the kelp into a high-value product. Dried kelp can be milled to any size, reducing volume for transport (Blikra et. al., 2020). Dried and milled kelp can be sold in this state or incorporated into other products. Dried kelp can be more expensive to produce in Alaska, especially when compared to other ambient preservation methods (Heidkamp et. al., 2022).

This study focused on reviewing the potential of forced air drying as a method for primary stabilization of kelp as ambient or solar assisted drying is impossible given the high humidity, frequent precipitation, and low temperatures (3-15° C) common during spring and early summer when kelp is at its prime and harvested in coastal Alaska. Other drying technologies such as freeze drying, fluidized bed drying, infrared assisted drying, vacuum drying, and microwave assisted drying may in some cases have slightly lower power costs, but the systems can be expensive, may require more space, require specialized maintenance and operational procedures, and may need intensive pre-processing for efficient drying (Xu et. al., 2014; Santhoshkumar et. al., 2023). Forced air drying systems are also simply constructed, consisting of a heating element, a circulation fan to move hot air through the drying chamber, and a ventilation fan to remove moist air from the chamber (Sappati 2020). Additionally, there can be mechanical or digital controllers to adjust the heating elements and fans as well as temperature and humidity loggers.

Some Alaskan communities face high power costs while others have access to low-cost renewable energy (Alaska Energy Authority 2022). Additionally, labor costs in Alaska remain high, between \$16-\$18 per hour (www.jobs.alaska.gov). Globally prices for dried kelp per kilogram are relatively low (\$3-\$12 USD) while the wholesale cost per wet, unprocessed kilogram for Alaskan kelp is relatively high (\$0.77-\$1.10 USD, Table 1., McKinley Research Group 2021, conversations with AK farmers). These factors contribute to the need for the development of efficient drying systems for the emerging Alaskan kelp industry to produce dried kelp products that can compete cost wise within domestic and global markets.

Table 1. Examples of Dried kelp prices in national and international markets compared to current prices for wet kelp.

Kelp Species	Processing Method	Price Range (USD/kg)	Source
<i>Laminaria japonica</i>	Dried Sliced Kelp	\$5.00 - \$8.00	Made-in-China
<i>Laminaria japonica</i>	Dried Kelp Sheets	\$4.90	Made-in-China
Wakame	Dried Cut Wakame	\$10.00 - \$12.00	Alibaba
Kelp, unspecified	Dried, Powdered, food grade	\$3.00 - 5.00	Alibaba
Sugar Kelp, famed, Alaska	Raw, from Farm	\$0.77 - \$1.10	Communication with Alaskan Farmers

Further hindering the development of efficient drying systems for Alaska is the lack of published information and peer reviewed studies on the performance of “off the shelf,” ready to purchase drying systems and associated costs to produce a dry kilogram of kelp. Similarly, if values are given, they are based on other kelp, algae, or other food products, not Alaskan kelp species. Alaska hosts unique species of kelps such as *Eualaria fistulosa* (range = Sitka, AK- Aleutian Islands, dragon kelp), *Nereocystis luetkeana* (range = Baja California-Aleutian Islands, AK, bull kelp), and the *Saccharina latissima* (range = sugar kelp, temperate waters NE Pacific and Atlantic Oceans) is different in texture from the same species grown in Atlantic waters (Lindeberg & Lindstrom 2024; Neiva et. al., 2018; Stekoll 2019). These kelps have not been dried on a large scale and are newly farmed species in Alaska. They have unique features, such as high alginate content, thick fleshy thalli, and tough fibrous mid ribs that can contribute to differences in drying performance and kinetics. Overall, these factors necessitate targeted research on optimized drying systems for Alaskan kelps.

To design an efficient drying system for Alaskan kelps several key parameters must be understood and can be derived from experimental drying trial data. The effective moisture diffusivity quantifies how quickly water migrates from within the kelp to its surface, informing optimal layer thickness and drying time (Sappati 2020). It reflects the internal mass transfer resistance and is a key indicator of drying efficiency and material behavior under drying conditions (Sappati et. al., 2017; Zhang et. al., 2022). The Page model constants describe the drying rate and curve shape, allowing accurate prediction of moisture loss over time (Sappati et. al., 2019; Zicheng et. al., 2022). The equilibrium moisture content estimated using models like Guggenheim-Anderson-de Boer, defines the drying endpoint and prevents energy waste (Aziz et. al., 2013; Uribe et. al. 2017). Together with estimates of drying efficiency and the influence of air temperature and humidity, these parameters enable precise control over the drying process, ensuring both energy efficiency and high product quality.

To date there have been few studies looking at the resultant compositional qualities of dried Alaskan kelp species, especially as they apply to utilization of dried kelp for human consumption, animal feed additives, and fertilizer. Large brown kelps in the Order Laminariales are known for sequestering high levels of iodine and heavy metals (Aakre et. al., 2021; Lüning & Mortensen 2015). The metals and iodine are concentrated in the drying process and can reach

levels that exceed regulatory and daily intake limits for humans and livestock (Delange 1993; Duinker et. al., 2020). Kelp is also host to numerous epiphytes and other organisms, particularly crustaceans such as amphipods and shrimp (Banach et. al., 2020; Lüning & Mortensen 2015). These organisms can persist through the drying process and end up in the final product where they may be at levels that could trigger allergic reactions in sensitive individuals (Mildenberger & Rebours 2025). Addressing these safety concerns as well as understanding the composition of dried Alaskan kelps is key to developing safe processing and handling protocols, food, animal feed additives, and other products with dried Alaskan kelps (Good et. al., 2021).

Objectives

Forced air drying for the primary stabilization of Alaskan kelps and milling of dried kelp products has been identified as a research priority yet few studies on the optimal methods for drying or resultant qualities of the dried kelps have been performed. Similarly, little data surrounding the drying of Alaskan kelps has been collected nor has there been an attempt to standardize this data collection. To address these knowledge gaps, the following objectives were identified and achieved through this project:

1.) Run drying trials on three species of Alaskan kelps that are currently farmed or have the potential to be farmed. *Saccharina latissima* (sugar kelp), *Nereocystis luetkeana* (bull kelp), and *E. fisulosa* (dragon kelp):

- a) Utilize a screw press to determine if lowering initial moisture content can reduce drying time.
- b) Collect data from the drying trials to determine important parameters that can be used to design an improved drying system such as effective moisture diffusivity, modeling constants to derive drying rate and curve shape, and equilibrium moisture content.
- c) Determine yield and cost parameters: drying time by volume (time/kg), wet to dry ratio (dry kg/wet kg), cost per dry kg.
- d) Determine power usage and resultant cost for the drying kelps based on a given cost per kWh and labor.
- e) Effectively mill dried kelps into a powder and package them in air-tight packaging for storage and transport.

2.) Run compositional analysis on the dried and milled kelps, utilizing a third-party lab, to determine the following:

- a) Fertilizer analysis
- b) Microbial safety
- c) Crustacean protein content (allergens)
- d) Heavy metals and iodine levels
- e) Human food nutritional analysis

Chapters

Chapter 1 Pre-treatment, Drying, and Milling of *Saccharina latissima* (sugar kelp), *Nereocystis luetkeana* (bull kelp), and *Eualaria fistulosa* (dragon kelp)

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Methods

Harvest and Transport

Kelp was harvested from the Alaska Ocean Farm's (AOF) lease near Woody Island in Kodiak, AK by the AOF harvest vessel and crew during June of 2024. The sugar kelp (*S. latissima*) and bull kelp (*N. luetkeana*) was harvested from commercially seeded farm lines and naturally established dragon kelp (*E. fistulosa*) was harvested from non-seeded structural lines of the farm. Kelp was removed from the lines using a knife, excluding the holdfasts. Wild bull kelp was harvested from the shoreline adjacent to the farm in March of 2025. The kelp was transported in 660 L insulated fish totes to the Kodiak Seafood and Marine Science Center and stored in the walk-in cooler at ~3°C until processing.

Screw Press

Sugar kelp and dragon kelp were run through a pneumatic screw press (Vincent Dewatering Screw Press, model CP-4, www.vincentcorp.com, complete specs in Appendix A) prior to drying. This was done to reduce moisture content and to shred the kelp to facilitate drying. The kelp was run through the press once and the residual blade material continued the drying process. The wet fraction extracted during pressing was reserved and frozen for later use and analysis outside of this project. The bull kelp was not run through the screw press as the equipment was not available at the time of harvest.

Drying

The drying trials were run using the Advanced Food Dehydrators Industrial Air Flow Model 156 Food Dehydrator (www.advancedfooddehydrators.com, complete specs in Appendix A). Data was collected from the temperature and humidity monitor on the drying system for both the interior drying chamber and the ambient conditions outside the drying chamber. All kelp was layered at 5 cm thickness to promote even drying and facilitate fitting on the dryer cart and rack system (Zhang et. al., 2022). The layers on the cart and rack system for this dryer were spaced too closely together (3 cm) to allow for a reasonable volume of kelp (≥ 5 cm) to fit, so only every other level of the cart system was utilized for drying kelp, for a total of 24 racks (Figure 1).



Figure 1. Dryer cart and shelving rack unit showing the rack spacing (left) and the cart loaded with the maximum 24 racks of kelp (right).

The drying cart and shelving rack unit did not come standard with non-stick perforated mats to facilitate the removal of dried product, prevent shredded product from falling through the stainless shelves, and prevent product from sticking. After one trial operating the dryer, it was determined that silicone mats were necessary, so a bulk roll of silicone matt with 25 mm holes was purchased and cut to fit the stainless shelves.

The kelp was dried at 70°C for 8 hours to attain a temperature that would kill most microbial organisms and attain <10% moisture throughout all the racks/shelves on the drying cart (Løvdalet al., 2021; Sørensen et al., 2023). This was based on small volume trials run prior to the full experimental drying trials. The kelp was allowed to cool to room temperature in the drying cabinet with the door closed before removal for milling. The relative humidity of the ambient space the dryer was housed in and the interior of the drying chamber was monitored with and recorded from a digital hygrometer that was built into the dryer (Elitech RCW-800W-THE, Appendix A.)

To determine important experimental constants (n and k in the Page model) and create drying curves for each species, samples of the kelps were collected at the end of each hour (1-8 hours, ± 5 min each side of the hour) during dryer operation and the percent moisture determined gravimetrically using a moisture balance (Ohaus MB 45-2A0). This was done for one drying run for each species. Samples were taken from the edge, midway to the center, and center of three racks (near the top, middle rack, near the bottom) and homogenized with a coffee grinder prior to measuring percent moisture. For the *N. luetkeana* with mixed blade and stipe, samples were collected of each type of tissue and homogenized, as with the other kelps.

Drying kinetics were modeled using the Page model: $MR = \exp(-k \cdot t^n)$ where MR is the moisture ratio, t is time in hours, k is the drying rate constant, and n is an empirical constant that describes the shape of the drying curve. The model parameters k and n were estimated by nonlinear least squares regression using RStudio (v.4.3.1). Initial values were set at $k = 0.01$ and $n = 1.5$, based on preliminary data exploration and values reported for brown seaweed species (Chen et. al., 2021; Ratti 2001). The fitting process minimized the residual sum of squares between observed and predicted MR values. Although a log-linear transformation of the Page model ($\ln(-\ln MR) = \ln(k) + n \cdot \ln(t)$) was used to visualize curve linearity and aid interpretation, final parameter estimates were derived from the nonlinear form. Moisture ratio values were plotted against time to generate drying curves, which exhibited sigmoidal form, supporting the applicability of the Page model to describe the drying behavior of kelp samples.

The data collected were used to estimate the drying rate with area (DR_A), equilibrium moisture content (EMC), drying performance, and effective moisture diffusivity (D_{eff}). These parameters are crucial to understanding, as well as estimating, the performance of a drying system, based on material characteristics, which are unique to kelp. The following equations were used to derive these parameters:

$$\text{Drying Rate with Area: } DR_A = ((M_i - M_f) \cdot W) / (A \cdot t)$$

DR_A is the drying rate over a given area, M_i is the initial moisture content of the kelp, M_f is the final moisture content of the kelp, W = the initial (wet) weight of the material, A is the surface area of the product being dried, and t is the drying time. The surface area (A) of the kelp layers was $\sim 0.268387 \text{ m}^2$.

$$\text{Equilibrium Moisture Content: } M_e = (M_o \cdot c \cdot K \cdot a_w) / ((1 - K \cdot a_w)(1 - K \cdot a_w + c \cdot K \cdot a_w))$$

M_e is the equilibrium moisture content and is defined as the moisture content at which a material is in balance with the surrounding atmosphere and the point where it will neither gain nor lose moisture. M_o is the monolayer moisture content where food is most stable and there is no microbial growth and little to no enzymatic activity. C is the water binding energy of the first moisture layer with higher values being more stable (Moreira et. al. 2016). K describes the difference in free enthalpy (Gibbs energy) between the multilayer water molecules and bulk liquid water. M_o , C , and K must be determined experimentally; by exposing the dried kelp to known relative humidities at constant temperature and letting it reach moisture equilibrium and measuring the resultant water activity levels (Chelno et. al., 2018; Tolstorebrov et. al., 2018). This was not possible for this experiment as the necessary equipment was lacking (environmental chambers and saturated salt solutions) so values from another study with *S. latissima* were substituted for all species dried. The values used were as follows: $M_o = 0.162$, $c = 2.14$, and $K = 0.998$ (Sappati et. al., 2017). These reference values and the final values for water activity from the trials were used to estimate the EMC.

Drying Performance was calculated through two metrics, determination of drying speed, defined as the rate of water removal over time (kg H_2O /hour) and drying efficiency defined as water removed per unit of final dry mass (kg H_2O /kg dry, Hu et. al., 2022; Zhang et. al., 2022).

The Moisture Diffusivity (D_{eff}) of the kelp: $\ln(\text{MR}) = \ln(8/\pi^2) - (D_{\text{eff}} \cdot \pi^2 \cdot t) / 4L^2$

Effective moisture diffusivity was calculated for each trial using a linearized form of Fick's second law for moisture diffusion in a slab geometry (Sappati et. al., 2017; Vega-Gálvez et. al., 2008). The equation was rearranged to a linear form, where MR is the moisture ratio, t is the drying time in seconds, and L is the half-thickness of the sample (0.025 m, based on 5 cm thick layers). For each trial, $\ln(\text{MR})$ was regressed against time to determine the slope (b), and D_{eff} was calculated as $D_{\text{eff}} = 4L \cdot b / \pi^2$. Only moisture ratio values between 0 and 1 were included. Linear regression was performed in R (v4.3.1), and estimated D_{eff} values were summarized by species and processing method. Bootstrap resampling (10,000 replicates) was used to estimate confidence intervals for the difference in mean D_{eff} between pressed and unpressed samples.

Milling

Kelp was milled to a powder (<1 mm particle size) using a hammer mill with adjustable screen size (Schutte Hammermill Mini Mill, www.hamtermills.com, complete specs in Appendix A).

Packaging

Post milling the kelp was packaged in heat sealed aluminum lined plastic bags with a re-sealable zip type closure. The kelp was weighed on a balance to ~227 g (0.5 lbs.) and added to the bag. The bags were then heat sealed and labeled with the common name, species name, date/lot code, and vendor contact information. Examples of the packaging can be found on the product specification sheets in Appendix B. The final dry yield for the trials was calculated at this step as the final weight of the dried and milled kelp bagged.

Water Activity and Percent Moisture of Dried Kelp Pre and Post Drying

Water activity was measured using an AquaLab (4TE Duo) water activity meter. Percent moisture was determined using an Ohaus (MB 45-2A0) moisture balance. Measurements for both water activity and percent moisture were collected as the kelp was delivered from the farm before any processing, after pressing with the screw press (sugar and dragon kelp only), immediately after removal from the drying chamber each hour, and just after the drying cycle was complete.

Yield

Kelp was weighed before pressing, before drying and after milling. The percent recovery (PR) was determined by dividing the dry weight (DW) of the kelp post milling by the wet weight (WW) of kelp added to the dryer and multiplying this value by 100 ($\text{PR} = (\text{DW}/\text{WW}) \times 100$). If the kelp was put through the screw press the percent recovery (PR) was calculated by dividing the dry weight (DW) by the screw press weight (SPW) and multiplying this value by 100 ($\text{PR} = (\text{DW}/\text{SPW}) \times 100$).

Power Usage and Cost to Produce Dried Kelp

Power usage was determined by multiplying the drying time (DT) in hours by the wattage of the equipment ($(\text{DT} \times \text{watts})/1000 = \text{kWh}$, <https://www.energy.gov>). To determine the cost of the drying run the kWh was multiplied by the commercial cost per kilowatt hour ($\text{CkWh} = \$0.17 \text{ USD}$) in Kodiak, AK. To determine the cost per kilogram to dry kelp in the system the cost per

kilowatt hour was divided by the number of dried pounds produced (CkWh)/lbs. dried kelp = cost per kg. to dry kelp).

Screw press operational costs per kilogram of kelp were determined the same as the drying costs. The wattage of the screw press was estimated to be ~1103 watts (manufacturer specification). The wattage for the dryer was estimated from the manufacturer to be about ~19,500 watts (manufacturer specification). The wattage of the hammer mill was estimated from the manufacturer to be about ~2238 watts (manufacturer specification).

The cost to produce the farmed kelp was set at \$1.10 USD/kg (\$0.50 USD/lb., AK industry average via farmer communication). Labor for processing (grinding raw kelp, loading and unloading the dryer, milling, packaging, and cleaning) was set at \$16.38 USD/hour, the local processing workforce average in Kodiak, AK (www.jobs.alaska.gov).

Data Processing

Data from drying trials, milling, water activity, and percent moisture analysis was entered directly in an Excel workbook. RStudio (v.4.3.1) was used to calculate the moisture ratio (MR) from the percent moisture data collected each hour and the equilibrium moisture content (EMC). Linear and nonlinear regression analysis of data and visualization of data was also performed using RStudio (v.4.3.1). Differences between means were identified by one-factor analysis of variance (ANOVA) were utilized where applicable and bootstrapping (95% confidence intervals, including zero) were also performed in RStudio (v.4.3.1).

Results

Yield

Percent yield, defined as the ratio of dry mass to initial wet mass, was used to evaluate retention of biomass across species and processing methods. Yield values ranged from approximately 6.268% (*N. luetkeana* wild blade material) to 13.498% (*S. latissima*) across all trials (Table 2., Figure 2.). Statistical analysis revealed no significant differences in percent yield between species (*Kruskal-Wallis test*, $p > 0.05$) or between processing treatments (*Wilcoxon rank-sum test*, $p > 0.05$). These findings suggest that, under the drying conditions used, neither species identity nor mechanical pressing had a significant effect on overall dry matter retention. Despite observable variability between trials, the consistency in yield outcomes indicates that drying efficiency, in terms of mass retention, was largely stable across the treatments evaluated. While biological differences between species exist, they may be less influential on percent moisture than the drying system's ambient conditions or may require larger sample sizes to detect.

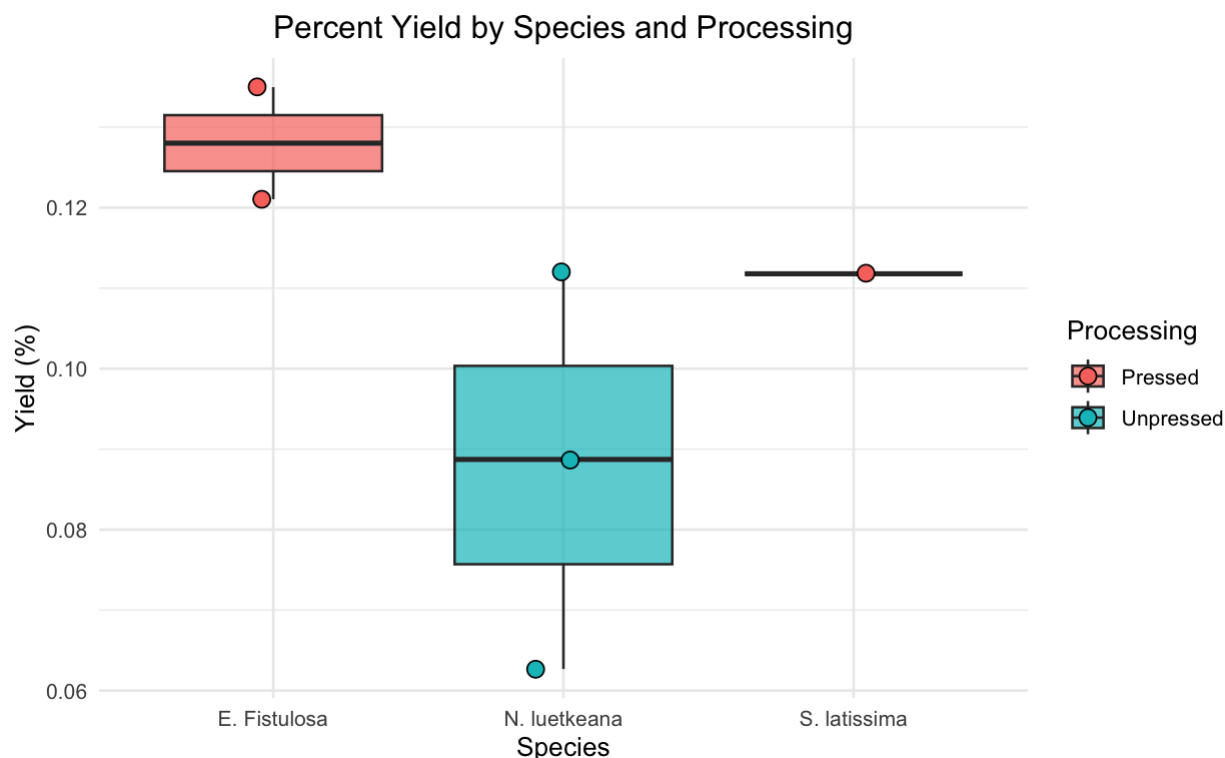


Figure 2. Percent yield by species and by pre-processing method (mechanically pressed or unpressed) based on drying trials for *Saccharina latissima* (sugar kelp), *Nereocystis luetkeana* (bull kelp), and *Eualaria fistulosa* (dragon kelp) dried at 70 °C.

Table 2. Fresh weight, dry weight, weight after screw pressing, and percent recovery (dry wt./fresh wt.) of dried and milled *Saccharina latissima* (sugar kelp), *Nereocystis luetkeana* (bull kelp), and *Eualaria fistulosa* (dragon kelp) dried at 70 °C. * There are no screw press weight values for *N. luetkeana* due to the screw press not being available.

Species	Trial Date	Fresh wt. kg	Screw Press wt. kg*	Dry wt. kg	% Recovery
<i>S. latissima</i>	7/22/2024	45.214	34.468	3.853	11.178
<i>N. luetkeana</i> (farmed, blade and stipe)	6/28/2024	45.074	NA	3.999	11.091
<i>N. luetkeana</i> (wild, blade)	3/13/2025	45.916	NA	2.878	6.268
<i>N. luetkeana</i> (wild, blade)	3/14/2025	34.205	NA	3.830	11.197
<i>E. fistulosa</i>	7/23/2024	47.650	34.910	4.712	13.498
<i>E. fistulosa</i>	7/24/2024	19.400	14.580	1.765	12.106

Moisture Content and Water Activity

Percent moisture content and water activity are listed for each species in Table 3. The species with the highest initial percent moisture was the *N. luetkeana* wild blade material processed on 3/13/2025 and the lowest percent moisture was from *E. fistulosa* processed on 7/24/2024. The highest pressed percent moisture was from *S. latissima* processed on 7/22/2024 and the lowest pressed percent moisture was for *E. fistulosa* processed on 7/23/2024. The highest percent moisture value for dried and milled kelp was for *E. fistulosa* processed on 7/24/2024 and the lowest percent moisture value for dried kelp was for *N. luetkeana* wild blade material processed on 3/14/2024. The highest value for water activity was from *N. luetkeana* farmed blade and stipe processed on 3/13/2025 and the lowest value for *E. fistulosa* processed on 7/23/2024.

Table 3. Fresh percent moisture, percent moisture after screw pressing, dry percent moisture, and water activity (w_a) of dried and milled *Saccharina latissima* (sugar kelp), *Nereocystis luetkeana* (bull kelp), and *Eualaria fistulosa* (dragon kelp) dried at 70 °C. * There are no screw press percent moisture values for *N. luetkeana* due to the screw press not being available.

Species	Trial Date	% Fresh	% Pressed	% Dry	w_a
<i>S. latissima</i>	7/22/2024	96.893	92.031	7.881	0.321
<i>N. luetkeana</i> (farmed, blade and stipe)	6/28/2024	94.327	NA	7.910	0.377
<i>N. luetkeana</i> (wild, blade)	3/13/2025	97.409	NA	8.299	0.202
<i>N. luetkeana</i> (wild, blade)	3/14/2025	98.136	NA	7.437	0.213
<i>E. fistulosa</i>	7/23/2024	94.271	81.369	9.321	0.202
<i>E. fistulosa</i>	7/24/2024	93.842	84.745	8.473	0.236

Guggenheim-Anderson-de Boer Model (GAB) to Determine Equilibrium Moisture Content

Equilibrium moisture content (EMC) was estimated for each trial using the Guggenheim-Anderson-de Boer (GAB) model based on measured final water activity values. EMC values ranged from approximately 0.14634547 to 0.07125325 g H₂O/g dry matter across species and processing methods (Table 4). Statistical comparisons revealed no significant differences in EMC by species (*Kruskal-Wallis test*, $p > 0.05$) or by pre-treatment method (pressed vs. unpressed; *Wilcox rank-sum test*, $p > 0.05$). These results suggest that under the controlled drying conditions used in this study, the final equilibrium moisture levels achieved by different species and processing methods were generally similar, reflecting the strong influence of environmental drying parameters (temperature, humidity) on the endpoint moisture content. While biological differences between species exist, they may be less influential on EMC than the drying system's ambient conditions or may require larger sample sizes to detect

Table 4. Values for equilibrium moisture content (EMC) derived from the Guggenheim-Anderson-de Boer Model (GAB) for dried and milled *Saccharina latissima* (sugar kelp), *Nereocystis luetkeana* (bull kelp), and *Eualaria fistulosa* (dragon kelp) dried at 70 °C. Constants M_o , C , and K could not be determined experimentally for each species so the following values from a drying study with *S. latissima* were substituted: $M_o = 0.162$, $c = 2.14$, and $K = 0.998$ (Sappati et. al., 2017).

Species	Trial Date	EMC
<i>S. latissima</i>	7/22/2024	0.11969756
<i>N. luetkeana</i> (farmed, blade and stipe)	6/28/2024	0.14634547
<i>N. luetkeana</i> (wild, blade)	3/13/2025	0.07125325
<i>E. fistulosa</i>	7/23/2024	0.07129081

Moisture Ratios (MR) via the Page Model

Moisture ratios (MR) were modeled using the Page equation, with parameters derived through nonlinear least squares regression. The natural logarithm of MR was plotted against the logarithm of drying time to estimate the empirical constants k (drying rate constant) and n (drying curve exponent) for each trial (Figure 3). The highest drying rate (k) was observed in the trial involving farmed *Eualaria fistulosa* on 7/23/24, while the lowest k value occurred in *Nereocystis luetkeana* blade samples dried on 3/13/24. The resulting k and n values were used to generate predictive drying curves, which were then compared to the observed MR values (Figure 4). Summary statistics and parameter estimates for each trial are provided in Table 5.

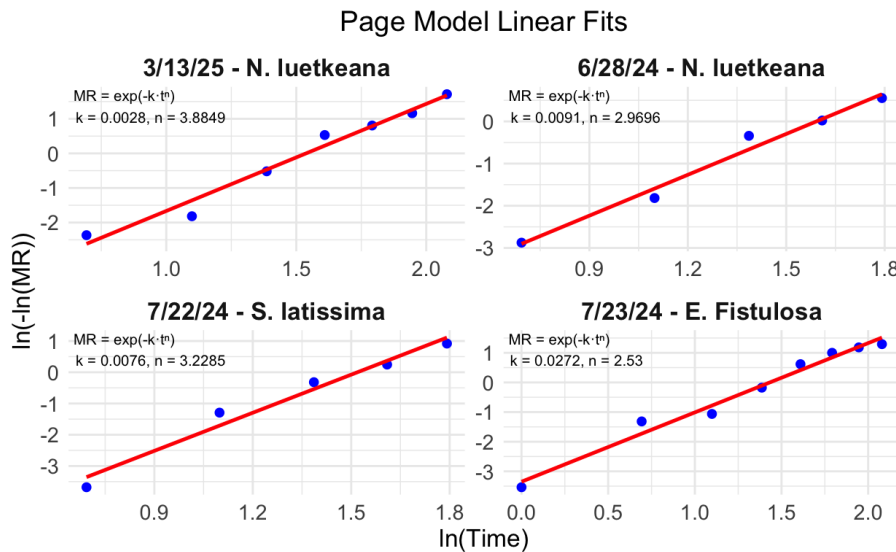


Figure 3. Resultant plots for moisture ratio (MR, blue dots) and Page model linear best fit (red line) to derive constants k and n for dried and milled *Saccharina latissima* (sugar kelp), *Nereocystis luetkeana* (bull kelp), and *Eualaria fistulosa* (dragon kelp) dried at 70 °C.

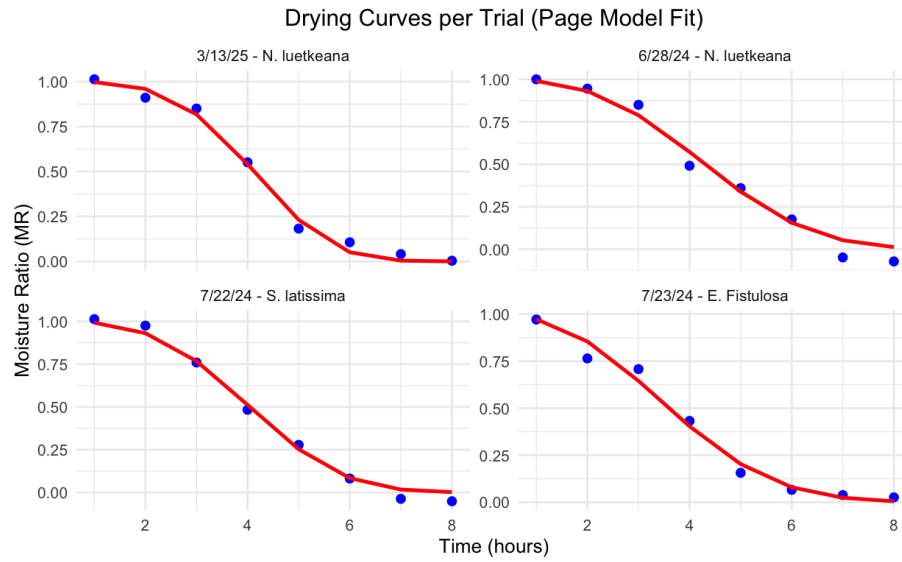


Figure 4. Resultant plots for moisture ratio (MR, blue dots) and Page model curves (red line) for dried and milled *Saccharina latissima* (sugar kelp), *Nereocystis luetkeana* (bull kelp), and *Eualaria fistulosa* (dragon kelp) dried at 70 °C.

Table 5. The moisture ratio (MR) and estimated values for constants k and n in the Page model for dried and milled samples taken each hour during the drying trials of *Saccharina latissima* (sugar kelp), *Nereocystis luetkeana* (bull kelp), and *Eualaria fistulosa* (dragon kelp) dried at 70 °C.

Species	Trial Date	Sample Hour	MR	k	n
<i>S. latissima</i>	7/22/2024	2	0.97509087	0.00762159	3.22847005
		3	0.75979006		
		4	0.48302401		
		5	0.27814419		
		6	0.08151976		
		7	-0.0373494		
		8	-0.0514977		
<i>N. luetkeana</i> (farmed, blade and stipe)	6/28/2024	2	0.94513989	0.0090878	2.96962572
		3	0.85000697		
		4	0.491414		
		5	0.35994554		
		6	0.17570188		
		7	-0.0480559		
		8	-0.0714616		
<i>N. luetkeana</i> (wild, blade)	3/13/2025	2	0.91038475	0.00282182	3.88491197
		3	0.85011198		
		4	0.5510967		
		5	0.18261385		
		6	0.1063759		
		7	0.04095359		
		8	0.00392476		
<i>E. fistulosa</i>	7/23/2024	2	0.76468815	0.02718078	2.52998426
		3	0.70781104		
		4	0.43238635		
		5	0.15655604		
		6	0.06592833		
		7	0.0381714		
		8	0.02614345		

Drying Rate with Area (DR_A)

Drying rate per unit area was evaluated across six kelp drying trials to determine variability in drying performance under different conditions. Drying rates, expressed in kilograms of water removed per square meter per hour ($\text{kg}/\text{m}^2\cdot\text{h}$), ranged from approximately 6 to $25 \text{ kg}/\text{m}^2\cdot\text{h}$, with no statistically significant differences observed among trials (*Kruskal-Wallis test*, $p = 0.416$). While variation in species and pre-treatment (e.g., pressing with the screw press) existed between trials, the drying system maintained relatively consistent performance per unit area. Notably, trials involving mechanically pressing kelp did not show a significantly higher drying rate per area when compared to unpressed trials (*Wilcoxon test*, $p > 0.05$, Figure 5.), indicating that pressing may not improve drying rate efficiency on a per-area basis under the drying conditions used. Similarly, there was no significant difference in drying rate among species (*Wilcoxon test*, $p > 0.05$, Figure 6). These findings suggest that system-level drying performance was stable, and that pressing alone at the pressure tested (20 psi) and species may not substantially reduce drying time or load on drying infrastructure in terms of area-based throughput.

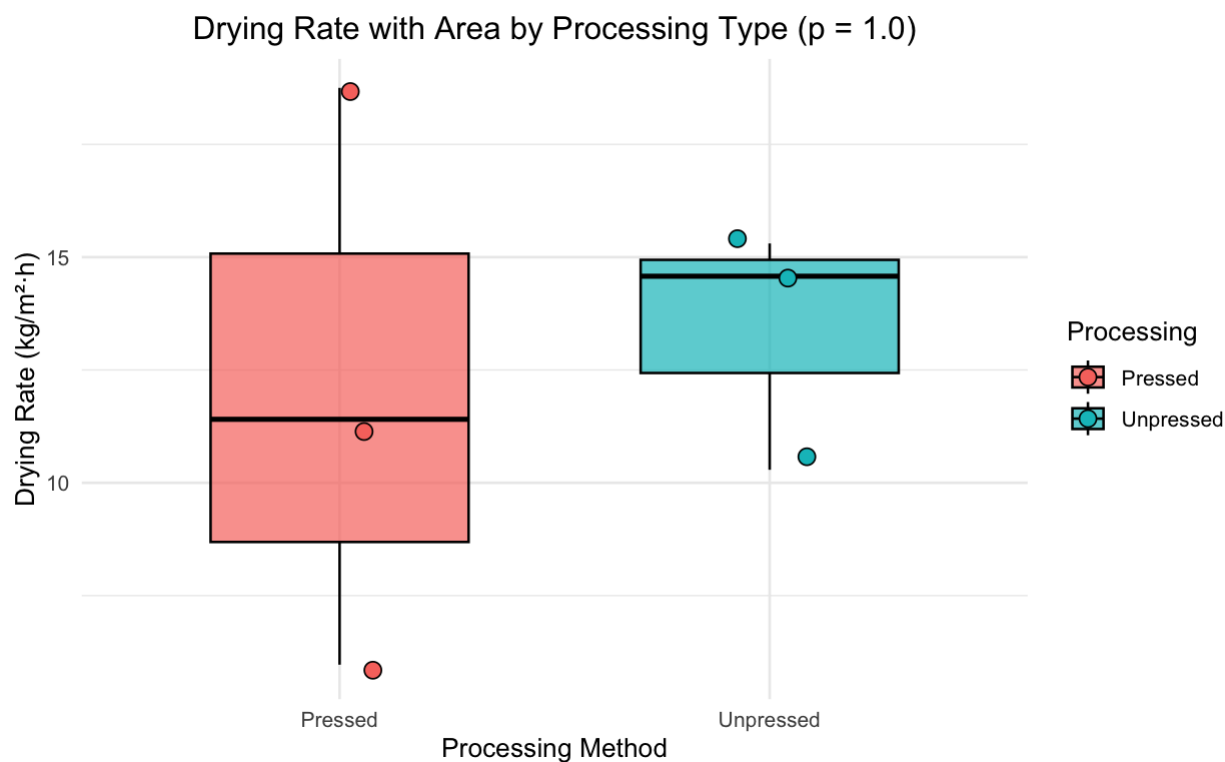


Figure 5. Drying rate with area ($\text{kg}/\text{m}^2\cdot\text{h}$), displayed by pre-processing method (mechanically pressed or not) estimated for the drying trials of *Saccharina latissima* (sugar kelp), *Nereocystis luetkeana* (bull kelp), and *Eualaria fistulosa* (dragon kelp) dried at 70°C .

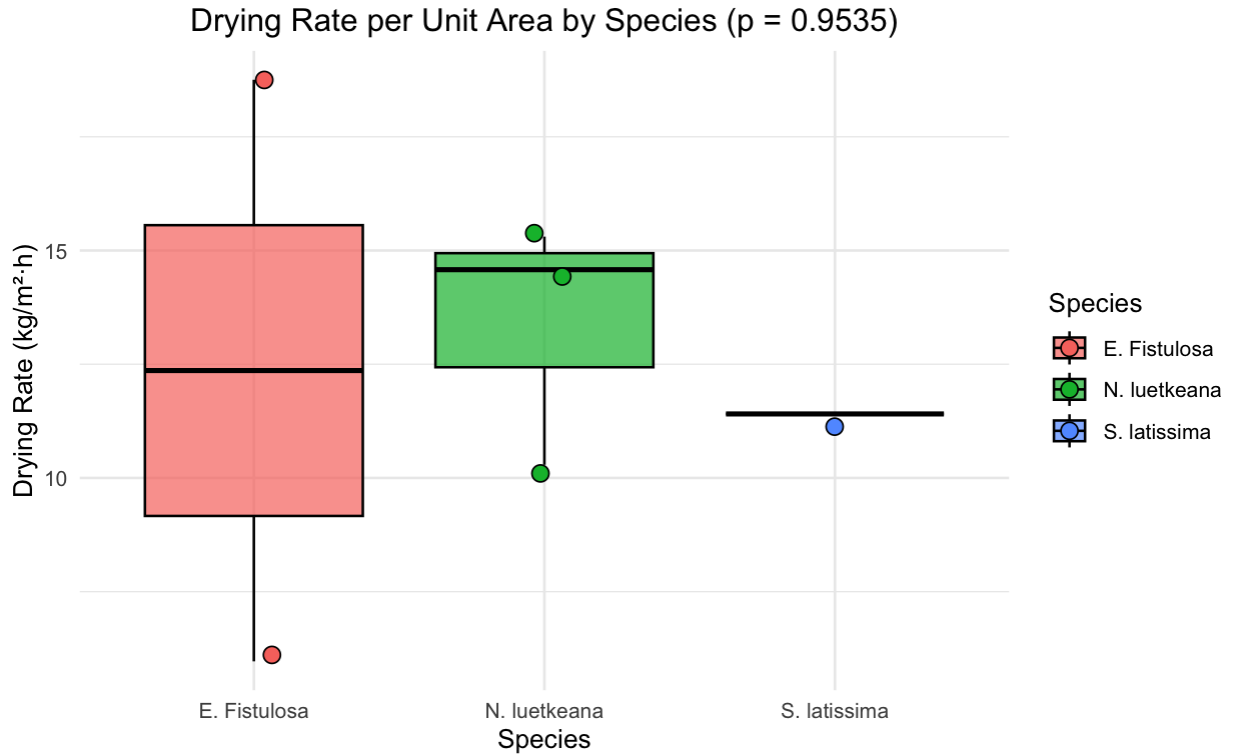


Figure 6. Drying rate with area ($\text{kg/m}^2 \cdot \text{h}$), displayed by species for the drying trials of *Saccharina latissima* (sugar kelp), *Nereocystis luetkeana* (bull kelp), and *Eualaria fistulosa* (dragon kelp) dried at 70°C .

Drying Performance

Drying performance was compared between pressed and unpressed kelp samples across six experimental trials. To evaluate whether pressing enhanced drying efficiency, two metrics were calculated: (1) drying speed, defined as the rate of water removal over time ($\text{kg H}_2\text{O}/\text{hour}$), and (2) drying efficiency, defined as water removed per unit of final dry mass ($\text{kg H}_2\text{O}/\text{kg dry kelp}$, Figure 7). Pressed and unpressed samples showed no significant difference in drying speed (Wilcoxon rank-sum test, $p > 0.05$), suggesting that pressing did not meaningfully increase the rate of water removal over time under the tested conditions. Similarly, drying efficiency was not significantly different between pressed and unpressed kelp ($W = 0$, $p = 0.1$). Although pressed kelp appeared to have higher drying efficiency ($\text{kg water lost per kg dry weight}$), this difference was not statistically significant (Wilcoxon rank-sum test, $p = 0.1$). A bootstrap power analysis based on the observed effect size indicated that the current sample size ($n = 3$ per group) had only $\sim 1.2\%$ power to detect a significant difference. This suggests that the study was underpowered, and that a larger sample size is needed to robustly test the effect of pressing on drying efficiency. These findings indicate that while pressing may reduce initial water load, it did not produce a statistically significant improvement in overall drying performance in terms of rate or efficiency. Further replication with larger sample sizes may be necessary to fully assess operational advantages of pressing.

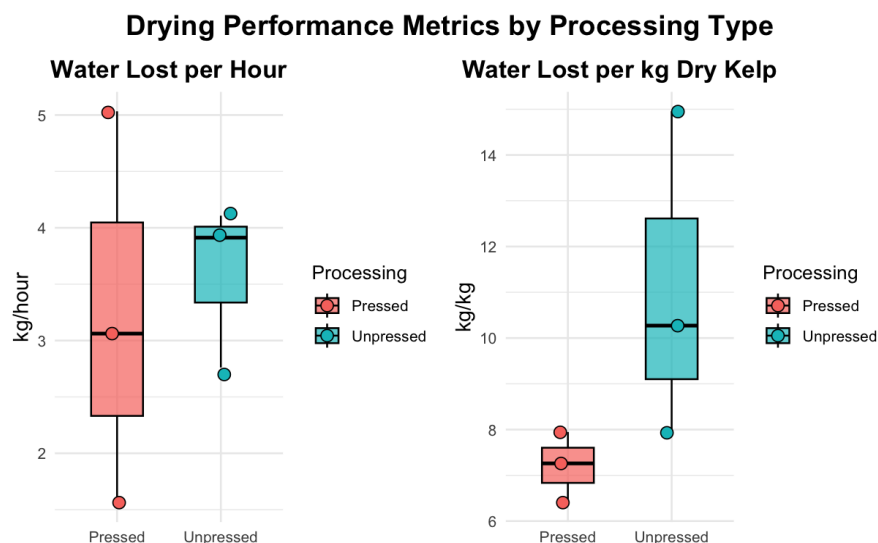


Figure 7. Drying performance illustrated as water loss per hour (kg H₂O/hour, right) and water loss per kg dry kelp (kg H₂O/kg dry kelp, left) for the drying trials of *Saccharina latissima* (sugar kelp), *Nereocystis luetkeana* (bull kelp), and *Eualaria fistulosa* (dragon kelp) dried at 70°C.

Effective Moisture Diffusivity (D_{eff})

Effective moisture diffusivity (D_{eff}) was estimated for each drying trial using a linearized form of Fick's second law for slab geometry. Estimated D_{eff} values ranged from 2.972356×10^{-8} to 6.043707×10^{-8} , falling within the typical range reported for high-moisture foods and brown seaweeds (Table 6). The highest diffusivity was observed in the trial involving *E. fistulosa* (7/23/24), while the lowest was recorded in *N. luetkeana* blade samples (3/13/24, Table 6). No significant differences in D_{eff} were detected between species (Kruskal-Wallis, $p > 0.05$) or between pressed and unpressed treatments (Wilcoxon rank-sum, $p = 1$). A bootstrap analysis of the mean difference in D_{eff} between processing methods further confirmed this result, with a 95% confidence interval that included zero.

Table 6. Moisture Diffusivity (D_{eff}) values estimated using a linearized form of Fick's second law for slab geometry ($\ln(MR) = \ln(8/\pi^2) - (D_{\text{eff}} \cdot \pi^2 \cdot t) / 4L^2$) for dried and milled samples taken each hour during the drying trials of *Saccharina latissima* (sugar kelp), *Nereocystis luetkeana* (bull kelp), and *Eualaria fistulosa* (dragon kelp) dried at 70°C.

Species	Trial Date	Processing Method	D_{eff}
<i>S. latissima</i>	7/22/2024	Pressed	4.199392×10^{-8}
<i>N. luetkeana</i> (farmed, blade and stipe)	6/28/2024	Unpressed	2.972356×10^{-8}
<i>N. luetkeana</i> (wild, blade)	3/13/2025	Unpressed	6.043707×10^{-8}
<i>E. fistulosa</i>	7/23/2024	Pressed	4.056621×10^{-8}

Milling

The hammer mill utilized for the trials was sufficient to match or exceed production rates in this study. The mill did exhibit some difficulty related to feed rate, with a minimum of 30 seconds needed between feeds of approximately 50 g of dried kelp. Optimal operational rotations per minute (RPM) was set at 2,500-2,600 for milling with the fine screen for powder (particles ≤ 1 mm). The mill has a fail-safe function where it will cease operation if the blades are impeded, and the operational RPM slows by 50 RPM from the set value. It was then necessary to turn off the mill, unplug it from power, open the feed chute exposing the grinding chamber, and physically remove kelp from the chamber. This procedure took two to three minutes. The *E. fistulosa* blade material and the lower stipe material from *N. luetkeana* was quite tough and if too much material was fed at one time the mill would bind and cease operations. The mill then had to be turned off and cleaned. There was little to no resistance with the correct feed rate for either *N. luetkeana* blade material or *S. latissima* blades.

The mill produced a great deal of dust, most of which was captured in the dust collection system consisting of a tote with a small shop vacuum attached to the lid to pull off and capture dust. It was noted that there was still visible dust rising from the feed chute while the mill was in operation.

Packaging

Packaging was simple and was achieved as described in the methods section. The labor of two people was sufficient to accomplish this task. One person portioned and weighed the kelp on the scale into the bag and another placed a silica desiccant pack into pre-labeled bags and then sealed them with the heat sealer. Each bag took about one minute to portion, weigh, and seal.

Power Usage and Cost to Produce Dried Kelp

The costs associated with drying and milling of the kelps is outlined in Table 7. The costs were the same among species and were determined by the operational hours of the dryer and the labor associated with preprocessing, loading the dryer, milling the dried kelp, and packaging. It took on average three hours of labor for two people to process the raw kelp into the final packaged milled kelp. Labor was the highest cost, averaging \$98.28 USD/dryer load. The cost to run the dryer was \$26.52 USD. The cost to operate the screw press, mill, and the circulation and vent fan on the dryer were nominal (between \$0.04-\$0.06 total for the load) and were not included in the analysis. This led to an estimated cost per kilogram of \$40.23 (Table 7). Forced air drying has the second highest kW use and the longest drying time compared to other drying technologies (Table 8).

Table 7. Power and labor costs to produce 1 kg of dried and milled kelp. All values in USD.

Cost from Farm	Power cost per 8h drying cycle	Labor Cost (3h x 2 employees)	Average kg Dried kelp per load	Cost per kg Dried kelp
\$16.41 (~32.81 kg wet kelp per dryer load)	\$26.52	\$98.28	3.51	\$40.23

Table 8. Power usage and drying times for various drying systems and dried products. *Note: Drying times are for 70° C.*

Drying System	Power Usage (kW)	Drying Time (H)	Food Type	Source
Freeze	0.7-1.5	Up to 24	NA	Harvest Right
Fluidized Bed	2 preheating, 5 drying	5	Pharmaceuticals	Barriga et. al., 2023
Infrared-Ultrasonic Assisted	0.37	5	Ginger Slices	Zhang et. al. 2023
Vacuum	65.97	1.67	<i>Saccharina japonica</i>	Xu et. al., 2023
Microwave	1.71-2.15	1.17	<i>Kappaphycus alvarezii</i>	Hakim et. al. 2020
Forced Air	19.5	8	<i>S. latissima</i> , <i>N. luetkeana</i> , and <i>E. fistulosa</i>	This study

Discussion and Industry and Research Implications

Overall, the small number of trials limited the ability to run analysis to determine if there were significant differences in drying performance among the kelp species. With only six trials total for three species, as well as inequality in pre-drying processing, the power to perform these analyses was lacking. This points to faults in how drying system suitability has been chosen by Alaskan kelp processors. Processors, prior to purchasing a drying system, may rely on the performance of one or two trials with Alaskan kelp species performed by the companies offering the dryers for sale. Similarly, purchase may be based on the performance of unrelated species or the same kelp species but from other geographical areas. Lack of replicates combined with differences in kelps used to determine drying system efficiency, as well as favorable bias from companies performing the trials, may lead to the purchase of suboptimal systems. Thus, it is recommended that these trials be repeated to increase the power of statistical analysis and should be performed by a third-party research institution with specific experience in drying science.

The goal of this study was to model realistic recoveries for the dried kelps through the drying and milling process. Percent recovery values for all species were between 6.268% - 13.498% (Table 2). Commonly reported percent recovery for kelps and other brown algae species are usually around 10% (Sappati 2020). The <10% percent recovery values for some of the trials could be attributed to a small amount of product loss through milling and bagging. It was noted that during the unloading of the drying racks there was the inevitable loss of some product on the floor of the processing plant or product retention on the drying racks. There was a small amount of powdered kelp that was lost during milling to the dust collection system. Modeled drying curves displayed negative values (GAB and Page models) after the 6th hour of

drying, indicating that some of the kelp was over-dried, perhaps leading to lower recovery rates. This loss was relatively small and would likely not constitute serious economic loss, especially when drying at scale.

The moisture ratios (MR) estimated using the Page model, were near or below zero prior to the end of the eight-hour drying cycle. This indicated some “overdrying” of the kelp had likely occurred, accounting for the reduction in mass below the usual 10% recovery. The eight-hour drying cycle was chosen because in pre-trials there was some kelp still left moist to the touch in the center of some of the racks. The eight hours ensured that all the kelp on the racks was fully dried. The undried kelp noted in the center of the racks on the drying cart was likely caused by a deficit of airflow to these racks. It was not possible to track airflow while the dryer was operating and the door was shut due to lack of equipment that was outside the scope and budget of this project.

Equilibrium Moisture Ratios (EMC) are important values for modeling drying efficiency via the Page model at different times and temperatures. Values for certain constants (M_o , C , and K) must be determined experimentally. However, this study lacked access to the proper equipment to perform the research to determine these parameters, experimentally. Thus, it is recommended that future drying research should include trials to determine these constants for all commercially grown Alaskan kelp species.

Based on the moisture diffusivity (D_{eff}) levels encountered in this study, the parameters used in this system were adequate to dry the kelp species tested. The values for D_{eff} were similar to other brown algae species (Table 9). However, it is notable that higher D_{eff} values were encountered in other studies (Table 9). These higher values were likely attributed to thinner layers of kelp used in the drying process. The trials run in this study utilized parameters that would likely be encountered in commercial drying production. Specifically, the drying system would be loaded to maximum capacity to optimize return on labor, hence why the 5 cm layer thickness was chosen. Thinner layers would likely dry more quickly, however, more frequent loading and unloading of the drying system likely would utilize more labor and thus increase drying costs.

The slightly lower D_{eff} for *N. luetkeana* farmed blade and stipe when compared to drying just the blade material indicated that the stipe material dries more slowly, and the system could be better optimized for drying the stipe material. Similarly, the stipe material could be cut into thinner sections prior to drying to facilitate moisture loss. The D_{eff} values calculated in this study could be used to inform the construction of a more efficient drying system for these kelps.

Table 9. Moisture Diffusivity (D_{eff}) values estimated using a linearized form of Fick's second law for slab geometry for dried and milled samples taken each hour during the drying trials of *Saccharina latissima* (sugar kelp), *Nereocystis luetkeana* (bull kelp), and *Eualaria fistulosa* (dragon kelp) compared to other brown algae species. Data from ** (Chenlo et. al., 2018), *** (Vega-Gálvez et. al., 2008).

Species	Drying Temp (°C)	Layer Thickness	D_{eff}
<i>S. latissima</i> , <i>N. luetkeana</i> , and <i>E. fistulosa</i>	70	5 cm	$2.972 \times 10^{-8} - 6.043 \times 10^{-8}$
<i>Ascophyllum nodosum</i> **	35-75	Single blade	$0.28 \times 10^{-9} - 0.54 \times 10^{-9}$
<i>Undaria pinnatifida</i> **	35-75	Single blade	$0.023 \times 10^{-9} - 0.042 \times 10^{-9}$
<i>Macrocystis pyrifera</i> ***	50-80	Single blade	$5.6 \times 10^{-9} - 10.2 \times 10^{-9}$

The jamming of the mill due to feed rate could be addressed with a properly adjusted conveyor feed system or by training processing staff to manually feed it with the proper timing. This timing would likely need to be adjusted, based on the species being processed, as some species had tougher, more fibrous material. The milling created a significant amount of dust which is an occupational hazard. Workers exposed to the dust from milling could suffer lung injury from breathing the fine particulate and accumulation of the dust on surfaces or buildup in the air could become a fire hazard. It is recommended that workers exposed to the dust use proper personal protective equipment (PPE, respirators, clothing, and eye protection). However, best practice is isolation of the risk – i.e. milling machines can be enclosed by thick plastic sheets or walls, or be installed into a room where it is the only operating equipment to reduce exposure to when the machine needs physical handling/maintenance. Regardless, it is recommended that a dust collection system be integrated into the milling line to reduce airborne dust hazards. The mill was also quite loud during operation, necessitating the use of auditory protection.

Metal fragments could enter the dried milled kelp as the blades of the mill wear over time and use. This could pose a serious health risk to end consumers. It is recommended that a magnetic collection system be integrated into the mill outflow to remove any potential metal fragments.

The dried, milled kelp created quite a bit of airborne dust during the packaging process. This could be abated by a dust collection system, and processing workers should wear the appropriate personal protective equipment (PPE, respirators, clothing, and eye protection) while packaging the milled kelp. The packaging process could be automated, reducing the need for personnel in this part of the manufacturing process, lowering exposure risk and lowering labor costs.

Given the costs associated with drying kelp in Kodiak, AK the average price to produce a kilogram of dried kelp is \$40.23 USD (Table 7). This is 3.35-13.41 times the average wholesale

prices of dried kelp available globally (Table 1). Labor was the greatest cost, at 3.71 times the cost of operating the dryer (Table 7). This illustrates how scale and automation of the drying and milling process is necessary to produce dried and milled kelp at prices competitive on global markets. It's important to note that although forced air drying has some of the highest kW usage rates among drying systems (Table 8), the other drying systems require more pre-processing such as grinding and pressing, and also require specialized operational and maintenance schedules. Forced-air drying is mechanically simple, easy to operate and maintain, hence why this system was chosen for this study. Remote, coastal Alaskan communities may not have access to personnel with the expertise to operate and maintain complex drying systems. Similarly, the complexity of operation and maintenance may make them overall more expensive to operate.

To be competitive drying at this scale, Alaskan processors would likely need to search for value in organic certification and the perceived value of products produced exclusively in Alaska. However, organic certification can be expensive (>\$1,000 USD/year, [Oregon Tilth](#)) adding to production costs. Also selling dried kelp into high value, higher priced markets such as those for human food products would be advantageous. It's also important to note that given higher power costs in other Alaskan communities, the costs associated with power use could be significantly more – for example, energy costs range from \$0.22 to \$0.80 per kWh in coastal Alaskan communities, depending on the time of year. Kodiak, AK has a large resident processing workforce with competitive labor pricing. It's also likely that labor inputs in other communities could be more expensive.

Chapter 2 Laboratory Analysis of the Fertilizer Components, Microbial Content, Shellfish Allergen Levels, Heavy Metal Content, and and Nutritional Analysis of Dried and Milled (*Saccharina latissima*), Bull (*Nereocystis luetkeana*), and Dragon Kelp (*Eualaria fistulosa*)

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Methods

Laboratory Analysis of Dried Kelp Samples

One kilogram of each species of dried kelp from one trial was homogenized through milling, packaged in air-tight packaging, and sent to a third-party laboratory for analysis. All dried and milled kelp samples were processed by Midwest Laboratories (www.midwestlabs.com) using the below outlined protocol and procedures.

Fertilizer Analysis

pH: equipment used = pH meter, Units = S.I., detection limit = 0.01 Analysis follows MWL WC 061 which is based on EPA 9045. The sample was mixed with water, and the pH of the resulting aqueous solution is measured.

Moisture: protocol followed= SM 2540 G, Units = %, detection limit = 0.1 Analysis follows MWL WC 060 which is based on SM 2540 G. The sample was weighed, placed in a vacuum drying oven to drive off the moisture, and re-weighed. The sample was then placed in a muffle furnace at 550°C, cooled, and re-weighed. The residue remaining was the ash and the mass lost was the volatile matter.

C and N: protocol followed = total carbon and nitrogen, Units = %, detection limit = 0.01 The sample was combusted in a pure oxygen environment within a furnace, converting carbon to CO₂ and nitrogen to N₂. The resulting gas was analyzed using infrared absorption for carbon and thermal conductivity for nitrogen, quantifying the total carbon and nitrogen content.

Phosphate (P₂O₅): protocol followed = ICP Analysis Fertilizers AOAC 985.01 (mod), Units = %, detection limit = 0.10. Analysis followed MWL ME 026 which is based on AOAC 985.01. Samples were prepared using MWL WC 056. Total minerals in fertilizers were prepared by AOAC 957.02 using mineral acids and heat. Water soluble manganese was prepared by AOAC 972.03 and the other water soluble by AOAC 977.01. Sample analysis involved moving the sample extract into the ICP where it was nebulized and introduced into the high temperature plasma which energizes the electrons of the dissolved minerals/metals. As the energized electrons of the minerals/metals return to ground state, energy is released as light. The emitted wavelength(s) and light intensities were used to identify and quantitate the minerals/metals in the sample.

Ammonium nitrogen (total): protocol followed = Ammonia (fertilizer/compost) (mod), Units = %, detection limit = 0.001. Analysis follows WC 015 which is based on AOAC 920.03. The sample was placed in a distillation tube and a standard base added to convert ammonium to ammonia. The ammonia was then distilled into an acid solution. The acid solution was titrated with a standard acid.

Carbon (total): protocol followed = Carbon/nitrogen in coal ASTM D 5373 (mod), Units = %, detection limit = 0.05. Sample analysis followed MWL PR 263 which references ASTM D 5373 (modified). Samples were placed in a combustion instrument where carbon was oxidized in oxygen to produce carbon dioxide and nitrogen compounds were converted to elemental nitrogen and the levels determined. The modification indicated is the matrix analyzed is not part of the ASTM scope.

Ash: protocol followed = SM 2540 G, Units = %, detection limit = 0.10. Analysis followed MWL WC 060 which is based on SM 2540 G. The sample was weighed, placed in a vacuum drying oven to drive off the moisture, and re-weighed. The sample was then placed in a muffle furnace at 550°C, cooled, and re-weighed. The residue remaining is the ash and the mass lost is the volatile matter.

Nitrate-Nitrogen: protocol followed = WC PROC 32, Units = %, detection limit = 0.01. The extraction phase is based on ASA (American Society of Agronomy) chapter 38 and uses potassium chloride as the extracting solution. The extract was analyzed by automated cadmium reduction based on EPA 353.2.

Potash (K₂O): Units = %, detection limit = 0.05; Sulfur (total): Units = ppm, detection limit = 0.05; Calcium (total): Units = %, detection limit = 0.01; Magnesium: Units = %, detection limit = 0.01; Manganese: Units = total ppm, detection limit = 20; Copper: Units = total ppm, detection limit = 20; Zinc (total): Units = total ppm, detection limit = 20; Boron (total): Units = total ppm, detection limit = 100; Sodium (total): Units = total ppm, detection limit = 20; Iron (total): Units = total ppm, detection limit = 20; protocol followed (all metals) = ICP Analysis Fertilizers AOAC 985.01 (mod) ppm or percent. Analysis followed MWL ME 026 which is based on AOAC 985.01. Samples were prepared using MWL WC 056. Total minerals in fertilizers were prepared by AOAC 957.02 using mineral acids and heat. Water soluble manganese was prepared by AOAC 972.03 and the other water soluble by AOAC 977.01. Sample analysis involved moving the sample extract into the ICP where it was nebulized and introduced into the high temperature plasma which energized the electrons of the dissolved minerals/metals. As the energized electrons of the minerals/metals return to ground state, energy is released as light. The emitted wavelength(s) and light intensities were used to identify and quantitate the minerals/metals in the sample.

Chloride: protocol followed = Chloride by Soil Sci. & Plant Anal. 1970, Units = %, detection limit = 0.01. Sample analysis follows MWL WC 054 which is based on a method published in the 1970 volume of Soil Science and Plant Analysis pp 1-6. The sample is extracted with dilute nitric acid and a silver nitrate solution is used to titrate the extract to a potentiometric end point.

N-P-K Ratios: were determined by using the results from the analysis for nitrogen, P₂O₅ and K₂O, which represent the percentages of each element/compound in the sample and rounding to the nearest whole number (Havlin et. al., 2013).

Microbial Testing

Aerobic Plate Count: protocol followed = AOAC 2015.13., 1970, Units = colony forming units (cfu)/g, detection limit = 10. Sample analysis follows MWL MI 293 which is based on AOAC 2015.13. A representative sample was obtained and added to the phosphate buffer. Aliquots of

the sample are withdrawn and placed on the Petrifilm plates. After the plates were prepared, they were incubated for 24 hours. After plates were incubated, the colonies found on the plates were counted and the levels reported as Colony Forming Units (cfu).

E. coli (generic) and Total coliforms: protocol followed = E. coli and Total Coliform using 3M Pertifilm, Units = colony forming units (cfu)/g, detection limit = 10. Sample analysis followed MWL MI 292 which is based on AOAC 2018.13. A representative sample was obtained and added to the phosphate buffer. Aliquots of the sample were withdrawn and placed on Petrifilm plates. The plates were incubated for 18 to 24 hours. After incubation, the plates were counted to determine the number of generic E. coli and total coliforms present. The color of the colony and the presence of gas differentiate a generic coliform from E. coli. The levels were reported as colony forming units (cfu).

Salmonella: protocol followed = Salmonella - Lateral Flow, Units = org/25g, detection limit = 1. Samples were analyzed following MWL MI 195 which is based on the RapidChek Select Salmonella User Guide. A representative sample was obtained and combined with a selective media and allowed to incubate. After incubation, a test strip was used for Salmonella determination. Results are reported as negative or presumptive positive.

Staphylococcus aureus: protocol followed = Staph aureus by 3M petrifilm by AOAC 2003.07, Units = colony forming units (cfu)/g, detection limit = 10. Sample analysis follows MWL MI 289 which is based on AOAC 2003.07 and AOAC 2003.11. Representative samples were obtained and added to the phosphate buffer at a ratio of 9 parts media to 1 part sample (9:1). Samples were placed on 3M Petrifilm and incubated for 24 hours. After the incubation period, plates were counted and reported as colony forming units.

Yeast and Mold counts: protocol followed = Yeast and mold FDA/BAM Chapter 18, Units = colony forming units (cfu)/g, detection limit = 10. Sample analysis follows MWL MI 288 which is based on FDA/BAM Chapter 18. A representative sample was obtained and added to the phosphate buffer. Sample aliquots were withdrawn, plated on PDA (potato dextrose agar), and incubated for five days. Colonies on the plates were counted as either yeast or mold and the results were reported as Colony Forming Units (cfu).

Crustacean Shellfish Allergens

Detection Limit = 10 ppm. Samples are analyzed following MWL FO 064 and employ the use of Enzyme Linked Immunosorbent Assay (ELISA). Samples are extracted and the extract placed in a series of wells coated with specific antibodies for tropomyosin. These antibodies capture the allergen (antigen) and a complex is formed. A second antibody containing an enzyme is then used to coat the fixed antigen-antibody complex and the enzyme acts on a substrate that is acted on by the enzyme and produces a product that is measured.

Iodine and Heavy Metals Analysis

Iodine (ppm): detection limit = 0.10; Arsenic (total): detection limit = 0.10; Cadmium (total): detection limit = 0.02; Lead (total): detection limit = 0.10; Mercury (total): detection limit = 0.01. protocol followed = ME 081, Units = ppm. Following an alkaline digestion, the sample was analyzed by use of inductively coupled plasma mass spectrometry (ICP-MS).

Nutritional Composition, Human Food

Sugars = Fructose, Sucrose, Maltose, Lactose: protocol followed = Sugar Profile, Units = % sugar, detection limit = 0.75. Analysis follows MWL HPLC 009 which is based on AOAC 982.14C (modified)/AACC 80-04.01 (modified). Samples were extracted with water and acetonitrile. Extracts were analyzed by HPLC (high pressure liquid chromatography) using a refractive index (RI) detector. The standard reporting level was 0.75 % for each mono- and disaccharide.

Fatty Acids = Trans Fatty Acids, Monounsaturated Fatty Acids, Polyunsaturated Fatty Acids, Saturated Fatty Acids: protocol followed = Fatty Acid Profile, Units = % of fat, detection limit = 0.10. Sample prep follows MWL HPLC 008 and analysis follows HPLC 004 which are both based on AOAC 996.06. The fat in the sample was extracted and saponified and the fatty acids methylated to form the fatty acid methyl esters (FAMES). The methyl ester extract (FAMES) was injected into a GC that uses a flame ionization detector (GC/FID). The response generated during analyses of the individual FAME was compared to standards which were used to quantitate the levels of fatty acids found in the sample. Individual FAME results were calculated from the total listed fatty acids.

Minerals (total) Calcium: detection limit = 0.20; Potassium: detection limit = 0.10; Sodium: detection limit = 0.25; Iron: detection limit = 5.0; protocol followed (all minerals) = ME 027; Units (all minerals) = ppm. Analysis follows MWL ME 027 which is based on AOAC 2011.14. Samples were prepared by MWL ME 077 using a wet ash process. Sample analysis involved moving the sample extract into the ICP where it was nebulized and introduced into the high temperature plasma which energized the electrons of the dissolved minerals/metals. As the energized electrons of the minerals/metals returned to ground state, energy was released as light. The emitted wavelength(s) and light intensities were used to identify and quantitate the minerals/metals in the sample.

Vitamin D3 (cholecalciferol): protocol followed = Fat Soluble Vitamin D, Units = $\mu\text{g/kg}$, detection limit = 4. Analysis follows HPLC 064 which is based on several sources including AOAC 2016.05. Sample was saponified and the fat containing cholecalciferol (vitamin D3) and ergocalciferol (vitamin D2) was extracted with organic solvent. The extracted vitamins were then derivatized to aid in Liquid chromatography–mass spectrometry (LCMSMS) analysis.

Data Processing

Data from Midwest Labs was received in PDF formatted reports and entered and reformatted in a Microsoft Excel spreadsheet. Data was processed into tables using Microsoft Excel.

Results

Fertilizer Analysis

Kelp samples from each species *Saccharina latissima* (sugar kelp), *Nereocystis luetkeana* (bull kelp), and *Eualaria fistulosa* (dragon kelp) were analyzed for primary and secondary nutrients, micronutrients, and percent carbon, nitrogen, and percent organic matter (Tables 10, 11, 12, and 13). *S. latissima* had the highest levels of nitrogen (elemental), phosphorus (P₂O₅), potassium (K₂O), fertilizer N-P-K ratio, and percent nitrogen. *S. latissima* had the lowest values for calcium, zinc, and the lowest C:N. *N. luetkeana* had the highest values for sodium, sulphur, magnesium, and iron. *N. luetkeana* had the lowest values for phosphorus (P₂O₅), boron, percent carbon, and percent organic matter. *E. fistulosa* had the highest values for calcium, zinc, boron, percent carbon, C:N ratio, and percent organic matter. *E. fistulosa* had the lowest values for sodium, nitrogen (elemental), potassium (K₂O), magnesium, iron, fertilizer N-P-K ratio, and percent nitrogen.

Table 10. Fertilizer analysis results for nitrogen (elemental) phosphorus (P₂O₅), potassium (K₂O), and secondary nutrients calcium (Ca), sulphur (S), magnesium (Mg), and sodium (Na) for dried and milled samples from drying trials of *Saccharina latissima* (sugar kelp), *Nereocystis luetkeana* (bull kelp), and *Eualaria fistulosa* (dragon kelp). All values listed as a percent.

Species	N	P ₂ O ₅	K ₂ O	Ca	S	Mg	Na
<i>S. latissima</i>	3.37	1.59	21.04	0.76	1.15	0.76	4.477
<i>N. luetkeana</i>	2.89	0.86	20.3	0.84	1.33	0.89	6.425
<i>E. fistulosa</i>	2.86	1.55	11.49	1.62	1.2	0.75	3.217

Table 11. Fertilizer analysis ratios (N-P-K) for dried and milled samples from drying trials of *Saccharina latissima* (sugar kelp), *Nereocystis luetkeana* (bull kelp), and *Eualaria fistulosa* (dragon kelp) compared to commercial liquid and dried kelp products currently marketed.

Species	N-P-K	Source
<i>S. latissima</i>	3-2-21	This study
<i>N. luetkeana</i>	3-1-20	This study
<i>E. fistulosa</i>	3-2-12	This study
FieldKelp (Cascadia Seaweed, <i>S. latissima</i> liquid extract)	trace-trace-trace	(https://www.cascadiaseaweed.com/biostimulants)
Dried <i>Ascophyllum nodosum</i> , Down to Earth all natural fertilizers	1-0.1-2	(https://downtoearthfertilizer.com/products/single-ingredients/kelp-meal-1-0-1-2/)

Table 12. Fertilizer analysis of micronutrient results for zinc (Zn), iron (Fe), and boron (B) for dried and milled samples from drying trials of *Saccharina latissima* (sugar kelp), *Nereocystis luetkeana* (bull kelp), and *Eualaria fistulosa* (dragon kelp). All values listed in parts per million (ppm). Although the samples were analyzed for manganese and copper, levels of these micronutrients were below detectable levels (20 ppm).

Species	Zn	Fe	B
<i>S. latissima</i>	34	249	182
<i>N. luetkeana</i>	38	295	0
<i>E. fistulosa</i>	87	190	225

Table 13. Fertilizer analysis of percent nitrogen (%N), percent carbon (%C), carbon to nitrogen molar ratio (C:N), and percent organic matter for dried and milled samples from drying trials of *Saccharina latissima* (sugar kelp), *Nereocystis luetkeana* (bull kelp), and *Eualaria fistulosa* (dragon kelp). All values listed as a percent.

Species	%N	%C	C:N	% Organic Matter
<i>S. latissima</i>	3.37	25.05	7 : 1	49.30
<i>N. luetkeana</i>	2.89	25.03	9 : 1	45.40
<i>E. fistulosa</i>	2.86	33.44	12 : 1	62.10

Microbial Testing

Microbial analysis results are illustrated in Table 14. Results for *E. coli*, coliform bacteria, yeast, molds, *Salmonella sp.*, and *Staphylococcus aureus* were below detection limits for all species of kelp tested. Samples of *E. fistulosa* and *S. latissima* did produce colonies of non-speciated aerobic bacteria (570 cfu and 1,620 cfu respectively) however the counts were well below regulatory limits for other dried, shelf stable food products such as spices (<10,000 cfu, Table 14).

Table 14. Microbial testing results for dried and milled samples from drying trials of *Saccharina latissima* (sugar kelp), *Nereocystis luetkeana* (bull kelp), and *Eualaria fistulosa* (dragon kelp) compared to the regulatory limits for dried spices. Values in colony forming units (CFU) excluding *Salmonella* which is listed as either positive or negative for pathogen detection.

* *International acceptable limits from (Sagoo et. al., 2009).*

Species	Aerobic Bacteria	E. coli	Coliforms	yeast	Mold	Salmonella	S. aureus
<i>S. latissima</i>	1620	<10	<10	<10	<10	Negative	<10
<i>N. luetkeana</i>	<10	<10	<10	<10	<10	Negative	<10
<i>E. fistulosa</i>	570	<10	<10	<10	<10	Negative	<10
Dried Spices*	10-10,000	10-100	<10	1000	1000	Negative	<10

Crustacean Shellfish Allergens

Milled samples from drying trials of *S. latissima* (sugar kelp), *N. luetkeana* (bull kelp), and *E. fistulosa* (dragon kelp) were tested for crustacean shellfish allergens, specifically tropomyosin. All samples showed a presence of shellfish allergens with the highest values noted for *E. fistulosa* and the lowest values for *N. luetkeana* (Table 15). All allergen levels for the dried kelps in this study were higher than in other studies (Table 15).

Table 15. Crustacean shellfish allergen (tropomyosin) levels for dried and milled samples from drying trials of *Saccharina latissima* (sugar kelp), *Nereocystis luetkeana* (bull kelp), and *Eualaria fistulosa* (dragon kelp) compared to results for **Alaria esculenta* and **S. latissima* values from Mildenberger et. al., 2025.

Species	Crustacean Allergens (mg/kg)
<i>S. latissima</i>	34
<i>N. luetkeana</i>	28
<i>E. fistulosa</i>	130
<i>Alaria esculenta</i> *	1 to 20.6
<i>S. latissima</i> *	1 to 3.9

Heavy Metals and Iodine

Dried and milled samples from drying trials of *S. latissima* (sugar kelp), *N. luetkeana* and *Eualaria fistulosa* (dragon kelp) were tested for levels of the heavy metals arsenic, cadmium, lead, and mercury (Table 16). All three species tested below the regulatory limits for both the WHO and California's Proposition 65 NSRL for lead and mercury per one gram sample. *S. latissima* and *N. luetkeana* tested above regulatory limits for both agencies in a one gram sample for cadmium with *N. luetkeana* just slightly over the Proposition 65 No Significant Risk Level maximum (4.921 µg/g measured, 4.1 µg/daily - oral NSRL maximum) and nearly two and a half times the Codex Alimentarius regulatory limit in similar foods (Table 16). Arsenic levels were significantly higher in a one gram sample for all three kelp species tested than any regulatory limits (Table 16).

All three kelps were also tested for iodine, an element many kelps and seaweeds contain in substantial amounts. *S. latissima* contained the highest iodine levels, followed by *N. luetkeana* and *E. fistulosa* having the lowest levels (Table 17). Iodine levels for a one gram of the dried and milled kelps ranged from ~26.25-2.25 times the USDA recommended daily allowance (RDA) for adult consumption (Pehrsson et. al., 2022, Table 17).

Table 16. Heavy metal levels for dried and milled samples from drying trials of *Saccharina latissima* (sugar kelp), *Nereocystis luetkeana* (bull kelp), and *Eualaria fistulosa* (dragon kelp) compared to regulatory maximum values from the Codex Alimentarius, CXS 193-1995, and the France Food Code (ANSES 2018). Prop 65 No Significant Risk Levels (NSRL) for daily oral consumption are also listed. *Due to lack of specific regulation for kelp, values for similar products have been substituted.

Species	Arsenic (µg/g)	Cadmium (µg/g)	Lead (µg/g)	Mercury (µg/g)
<i>S. latissima</i>	86	2.92	0.16	0.01
<i>N. luetkeana</i>	58.2	4.921	0.14	0
<i>E. fistulosa</i>	66	0.48	0	0
Codex Alimentarius *	0.35 (rice)	2 (bivalve mollusks)	0.3 (fish)	0.01
France Food Code	<3	<0.5	<5	<0.1
Prop 65 NSRL	10 (µg/day -oral)	4.1 (µg/day-oral)	15 (µg/day -oral)	NA

Table 17. Iodine levels for dried and milled samples from drying trials of *Saccharina latissima* (sugar kelp), *Nereocystis luetkeana* (bull kelp), and *Eualaria fistulosa* (dragon kelp) compared to USDA recommended daily allowance (RDA) for adults (Pehrsson et. al., 2022).

Species	Iodine (µg/g)
<i>S. latissima</i>	3,940
<i>N. luetkeana</i>	1,330
<i>E. fistulosa</i>	338
USDA-RDA	150 (µg)

Nutritional Composition, Human Food

Dried and milled samples from drying trials of *S. latissima*, *N. luetkeana*, and *E. fistulosa* were analyzed for human nutritional composition. Data from these analyses was used to create the nutritional labels in Figure 8. Serving sizes for the nutritional labels were governed by the high iodine content, hence the one teaspoon (~3.65 g) and quarter teaspoon (~0.90 g) serving sizes.

S. latissima and *N. luetkeana*, had the highest ash contents (44.1% and 44.8%, respectively) while *E. fistulosa* had the lowest ash content (25.8%, Table 18). All three species were relatively high in fiber with *E. fistulosa* having the highest percent fiber (Table 18). Interestingly, *E. fistulosa* had the highest carbohydrate content followed by *S. latissima* and *N. luetkeana* (Table 18). Carbohydrates in the three kelps were predominantly fiber sugars (Table 19). It is important to note that other long chain sugars common in kelps were not analyzed or enumerated as part of this standard nutritional panel analysis. The composition of fat in the kelps is displayed in Table 20. with all species having a similar breakdown of poly, mono, and

saturated fatty acids. Fat content was relatively low and similar in all species (3.2%-3%). Protein content was highest in *S. latissima* (16.1 %) and near 14% for *E. fistulosa* and *N. luetkeana* (Table 18). All three species had relatively low caloric content per 100 g with *E. fistulosa* having the highest (276 calories), likely due to the higher carbohydrate percentage (Table 18). Mineral analysis in Table 21. shows the levels of iron, potassium, calcium, and sodium in the kelps. All three kelps had approximately 2%-4% of the USDA recommended allowance of these minerals except for *E. fistulosa* having around 6% of the USDA daily allowance of potassium (Figure 8).

Table 18. Percent ash, dietary fiber, carbohydrates, fat, protein, and calories for dried and milled samples from drying trials of *Saccharina latissima* (sugar kelp), *Nereocystis luetkeana* (bull kelp), and *Eualaria fistulosa* (dragon kelp).

Species	Ash	Dietary Fiber	Carbohydrates	Fat	Protein	Calories
<i>S. latissima</i>	44.1	34.1	33	3.2	16.1	225
<i>N. luetkeana</i>	44.8	27.4	31.2	3	13.7	207
<i>E. fistulosa</i>	25.8	42.3	48.5	3	13.8	276

Table 19. Percent total sugars, glucose, sucrose, and fiber sugar for dried and milled samples from drying trials of *Saccharina latissima* (sugar kelp), *Nereocystis luetkeana* (bull kelp), and *Eualaria fistulosa* (dragon kelp). Levels of sucrose or lactose were lower than the detection limit (< 0.8%).

Species	Total sugars	Glucose	Fructose	Fiber Sugar
<i>S. latissima</i>	7.6	4.3	3.3	41.7
<i>N. luetkeana</i>	6.7	6.7	0	34.1
<i>E. fistulosa</i>	9.3	9.3	0	54.6

Table 20. Percent polyunsaturated fatty acids, monounsaturated fatty acids, and saturated fatty acids for dried and milled samples from drying trials of *Saccharina latissima* (sugar kelp), *Nereocystis luetkeana* (bull kelp), and *Eualaria fistulosa* (dragon kelp). Levels of trans fatty acids were lower than the detection limit (< 0.1%).

Species	Polyunsaturated Fatty Acids	Monounsaturated Fatty Acids	Saturated Fatty Acids
<i>S. latissima</i>	52.9	18.5	28.6
<i>N. luetkeana</i>	56.9	14.3	28.8
<i>E. fistulosa</i>	53.4	18.8	27.8

Table 21. Iron, potassium, calcium, and sodium content in parts per million (ppm) for dried and milled samples from drying trials of *Saccharina latissima* (sugar kelp), *Nereocystis luetkeana* (bull kelp), and *Eualaria fistulosa* (dragon kelp).

Species	Iron	Potassium	Calcium	Sodium
<i>S. latissima</i>	176	15,1000	15,000	34,900
<i>N. luetkeana</i>	193	138,000	6,540	54,300
<i>E. fistulosa</i>	37.3	65,400	12,200	23,200

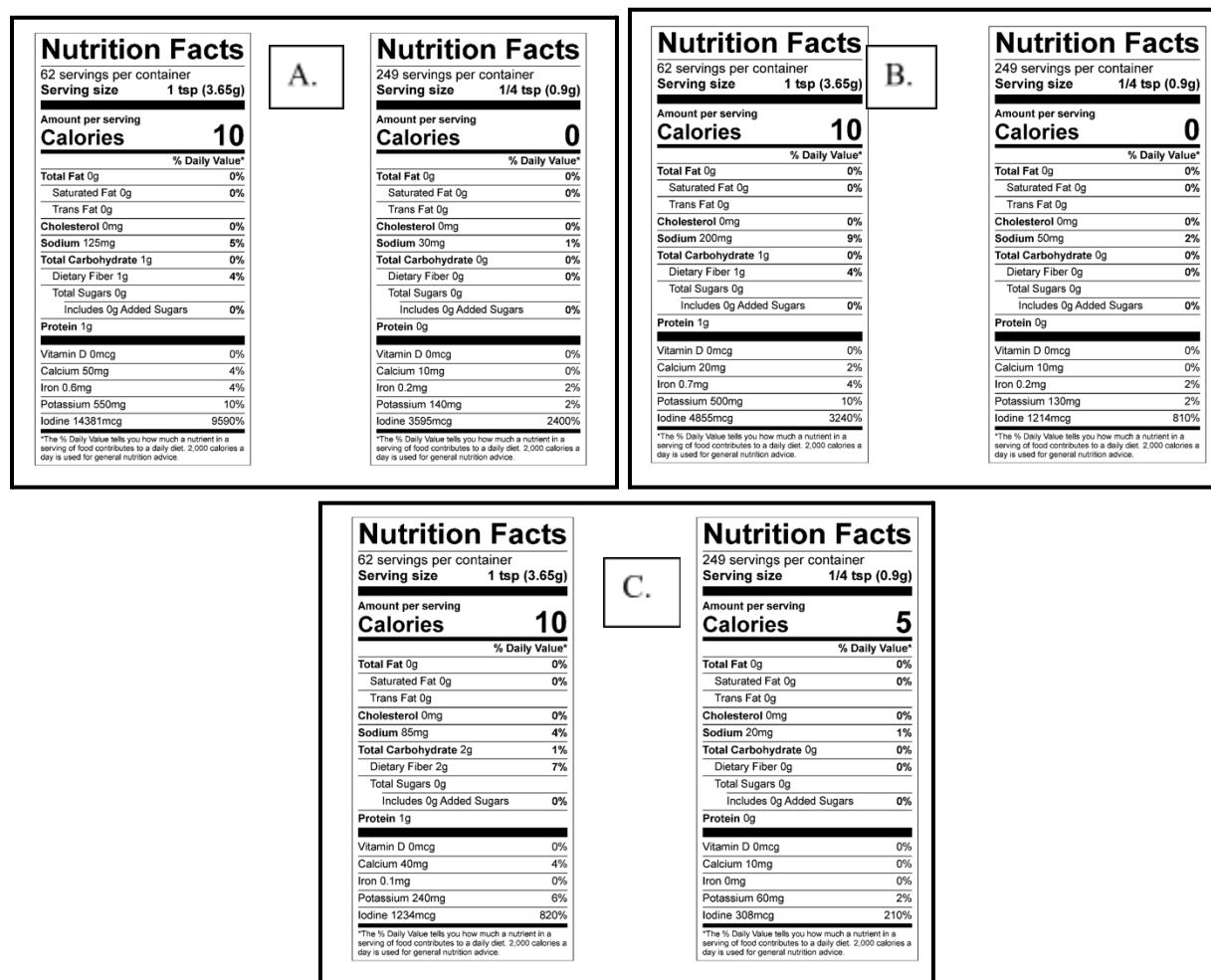


Figure 8. Nutritional labels produced by Midwest Laboratories from nutritional analysis data for dried and milled samples from drying trials of A. *Saccharina latissima* (sugar kelp), B. *Nereocystis luetkeana* (bull kelp), and C. *Eualaria fistulosa* (dragon kelp).

Discussion and Industry and Research Implications

The three species of kelp analyzed showed results for N-P-K similar to other studies (Menasha 2015; Nabti et. al., 2017; Zheng et. al., 2016). All three species of kelp had relatively high potassium levels. Kelp is typically utilized in the agricultural industry as a biostimulant, soil builder, or potash additive (Mouritsen et. al. 2021). The dried and milled kelp samples analyzed showed more nitrogen, phosphorus and potassium than commercially available kelp biostimulant products or dried kelp fertilizer/nutrient supplements from other seaweeds (Table 11).

The substantial amount of salt in the dried and milled kelp may be an issue if applied as a soil amendment in large quantities. However, the addition of kelp has been shown to reduce soil salt content and improve salinity tolerance in some terrestrial crops (Illera-Vives et. al., 2020). Pre-washing of the kelp could also be implemented to remove salt prior to drying. Field trials of the dried kelps produced in this study would need to be conducted to determine their impacts on soil health, chemistry, and crop performance. Due to the relatively high cost of production in this study (\$40.23 USD/kg) compared with the low retail cost of most dried kelp and seaweed fertilizers (\$8.62-15.69 USD/kg, Google Shopping), cheaper, scalable drying methodologies and equipment need to be identified for dried kelp fertilizer products produced with Alaskan kelp to be profitable.

The microbial analysis results with low or absent pathogenic and non-pathogenic bacterial, mold, and yeast CFUs indicates that the preprocessing, drying, and milling and packaging procedures used were sufficient to prevent the introduction or growth of pathogenic and non-pathogenic bacteria (Table 14). The remaining presence of some non-specified, aerobic bacteria, mold and yeast in some of the samples does allude to the drying temperature and duration perhaps being inadequate to inactivate all bacteria in the samples or that milling and packaging procedures could have introduced these organisms to the samples. It is therefore recommended that microbial testing of the kelp be performed at each step of processing to determine potential contamination points. It is also important to note that the water activity levels and packaging were sufficient to prevent the growth of pathogens, molds, and yeasts in storage, transport, and shipping (Water activity levels in Chapter 1, Table 3., WA = 0.202-0.377).

Kelps could contain levels of other pathogens, such as *Vibrio sp.* that could pose a threat to human health (Løvdaal et. al., 2021). Currently there are no national or international standards for microbial levels in seaweed and kelp products. It would be advantageous to the kelp and seaweed industry to establish microbiological standards for kelp and seaweeds.

The shellfish protein tropomyosin associated with crustacean shellfish was present in all the samples of dried kelp. The levels of this protein warrant declaration on product labeling, to alert consumers and avoid serious illness or death in sensitive individuals that could consume the product. The most commonly associated crustacean with the kelps were gammarid amphipods that live in the cultivated kelp. There are no pesticides approved for use in kelp farming in the US and these organisms are hard to remove from the kelp either during or post-harvest. Attempts could be made to introduce a removal step in processing to lower the number of these organisms present in the final product, however, this could add significant cost to processing. Similarly, complete removal of these organisms is not guaranteed, and even the presence of one organism could be problematic, triggering product recall and litigation. It is therefore recommended that

the dried kelps retain a product warning for this allergen. There is also the possibility of other allergens in the dried kelps, such as proteins from molluscan shellfish and fish. It is recommended that dried kelps undergo further testing for these allergens as well.

The levels of arsenic in the dried and milled kelp samples were high for all species tested. The test for arsenic was limited to reporting only elemental arsenic and did not differentiate between inorganic and organic arsenic species. Inorganic arsenic is cytotoxic, while organic arsenic is not (Andrewes et. al., 2004; Ma et. al., 2018). Regulatory levels set by the USDA and Prop 65 only pertain to inorganic arsenic. In other studies, kelps have been shown to be high in arsenic, but when speciated, the arsenic is present predominantly in organic forms, namely arsenosugars (Díaz et. al., 2019; Yu et. al., 2024). It is recommended that further testing be done on Alaskan dried kelp samples to determine the speciation of arsenic as this may be a way to circumvent labeling under Proposition 65. Similarly, cadmium can exist in kelps in organic forms and may thus have much lower levels of toxic inorganic cadmium. Lead and mercury in the samples was low/not detectable or near regulatory levels but still worthy of continued testing to assure buyers and consumers.

Iodine levels in the three dried kelps were high, as has been noted in other brown kelps (Lüning et. al. 2015). However, incidences of iodine toxicity from consumption of kelp are rare and high iodine levels contribute to the nutritional value of these kelps as iodine is an element critical for healthy thyroid function in mammals (Krzepilko et. al., 2015). The high levels could pose a risk of iodine toxicity through overconsumption and were thus used as the limiting factor in determination of serving size (Aakre et. al., 2021; Müssig et. al. 2006, Figure 8). Arsenic and cadmium could also be used to determine serving size. Other kelp and seaweed products do not list iodine on nutritional labels as it is currently not mandated if the iodine is naturally occurring. Only additions of iodine to foods need to be reported on nutritional labels (Pennington & Young 1990). The majority of dried kelp products do not report iodine levels or heavy metal levels on nutritional labels nor do the levels of these compounds determine serving size (Shaughnessy et. al., 2023).

Kelp and kelp products are often touted as low-calorie, nutrient dense foods. The nutritional analysis of dried and milled kelp of the three species showed high levels of important minerals such as calcium, iron, and potassium. Iodine was also high, this is both problematic and useful, as a teaspoon serving is orders of magnitude more than the USDA recommended daily and weekly consumption limits. The dried kelps analyzed in this study could thus be valuable as an iodine and mineral supplement. Currently, there are dozens of dried kelp iodine supplements for sale on online retailers such as Amazon. Organic certified, Alaskan kelps may have a niche in this market.

All kelps were low calorie per ~1 teaspoon serving size. The dried kelps were high in sodium, which may lend them to use as a sodium chloride replacement in foods, without adding a tremendous number of calories. Inclusion of kelp in food products such as seasonings may increase acceptability in western food markets as most consumers in these markets are not accustomed to consuming kelp. It may be advantageous to conduct research on consumer opinion on these dried kelp products to help advise the development of high-value food products or seasonings with these kelps (Gorman et. al., 2025; Moss et. al., 2024) Seasonings are some of

the most expensive food products by weight, and utilization of dried kelp in this manner may be a way to recover the high costs associated with drying (Banach et. al., 2020).

Publications

A summary of this report will be added to the Seaweed and Processing Guidelines for Alaska (Good et. al., 2022) published by the Alaska Sea Grant Program. This report, or an annotated version, may be submitted to up to three journals for publication later in 2025.

Product Specification Sheets

Product specification sheets were created for each of the three species of kelp using the compositional, nutritional, and food safety analysis data. A product spec sheet, or specification sheet, for food products outlines the quality, safety, and regulatory standards for a product. It's a critical document that helps food manufacturers ensure consistency and avoid product recall. Product spec sheets are critical documents presented to potential buyers to generate interest in wholesale sales from a product manufacturer. A product spec sheet can contain the following information: product description, including size, weight, color, and nutrient content, packaging and labeling requirements, inspection process details, storage and transportation conditions, allergen information, dietary preferences and restrictions, chemical composition, microbiological levels, and sensory attributes. Examples of the product spec sheets for each of the three species of kelp can be found in Appendix B of this report.

Outreach

Information collected in this study was publicly presented to a group of Kodiak Archipelago residents in the form of a one-day workshop hosted at the Kodiak Seafood and Marine Science Center with the support of the Alaska Sea Grant Program. Five individuals from four Kodiak archipelago communities attended the workshop. The workshop included both hands-on training with the dryer and mill as well as lectures on food safety, understanding laboratory testing and results, and product development.

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◆ **The Vincent Screw Press** is a continuous dewatering press, custom engineered for your application.

◆ The Vincent Press handles materials often considered unpressable, accepts variable feed rates and has low operating and maintenance costs.

◆ The CP/VP model screw presses are most commonly used in the following applications, but are not limited to this list:

Pulp and Paper
Corn Wet Milling
Citrus Peel
Spent Brewers Grain
Fruit and Veg. Juicing
Cellulosic Ethanol
Cooker Crumb
Spent Coffee
Tobacco
Pectin
Xanthan Gum
Nutraceuticals
SPC
Bioresin
Etc...



➔ **This VP-24 was built for Corn Wet Milling and is equipped with the optional inlet hopper screen.**



The CP-4 lab screw press is our most popular model. Results with it can be scaled to larger presses. ➔



➔ **The VP-24 screw presses are used in dewatering tobacco stems and dust.**



➔ The VP screw press is used in both virgin and recycle mills to press waste streams and screen rejects.



All of Vincent's screw presses can be made vapor tight and ATEX certified. This VP-24 is used in a pectin application. ➔



➔ All of Vincent's screw presses are made in America. Note this CP-10 has the CIP spray system option.

◆ The screw rotates inside a screen, forcing liquid through this screen. The screens are built with stainless steel profile bar (wedgewire) or reinforced perforated sheets.



◆ The screw has a graduated pitch with interrupted flighting to maximize dewatering and prevent co-rotation when paired with resistor teeth.



◆ Press cake moisture is controlled by a discharge cone, actuated by an air cylinder. This provides an additional level of dewatering control only offered by Vincent.



Vincent
CORPORATION

Appendix A. Screw Press, Dryer, and Mill Product Sheets Continued

Compact. Powerful. USDA-Compliant for Serious Production

The **AirFlow 156** is a compact industrial-grade dehydrator built for performance. Designed and manufactured in the USA, it offers the features and capacity that growing businesses need—without taking up unnecessary space. Whether you're producing jerky, pet treats, or dried fruits and vegetables, this model delivers even, efficient drying with precision temperature control and full USDA-compliant lethality cycle capabilities. It's a perfect fit for startup operations or established brands looking to expand production with confidence and safety at the forefront. <https://www.advancedfooddehydrators.com/airflow156.html>



Specifications: AirFlow 156 Commercial Food Dehydrator Drying Capacity

- **156 sq. ft. of tray area**
- **Holds approximately 156 lbs. of ¼" sliced beef jerky per batch**
- **Approximate dry time: 3.5 hours per batch**

Construction & Dimensions

- **Size: 97" L x 34" W x 78" H**
- **Weight: Approx. 1,200 lbs**
- **Frame: Heavy-duty welded 6061 T6 aluminum (same grade used in aircraft)**
- **Floor: 3/16" aluminum plate with welded joints**
- **Exterior: Heavy-duty .063 aluminum**

- **Interior Walls & Ceiling: .063 aluminum**
- **Insulation: 2" Class 1 polyisocyanurate in walls, ceiling, and floor**

Heating & Airflow

- **Heat Source: 19.5 kW electric heater elements**
- **Circulation Fan: Premium-efficiency, inverter-rated, sealed ball bearing fan (6,400 CFM)**
- **Exhaust Fan: EC motor, 100% speed-controllable**
- **Potentiometer to manage humidity and exhaust flow**

Appendix A. Screw Press, Dryer, and Mill Product Sheets Continued

Temperature Control

- **Commercial-grade digital temperature controller**
- **Integrated digital timer to auto shut-off**
- **Can reach USDA lethality requirements before dehydration**
- **Maximum temperature: 200°F**

Racking System

- **Extra heavy-duty aluminum roll-in/out rack**
- **Tray spacing: 1.25"**
- **Includes 48 stainless steel trays (18" × 26" heavy-duty grilles)**

Compliance & Safety

- **Lethality Cook Cycle built-in (USDA-recommended for meat jerky production)**
- **Data logger for temperature and humidity tracking (downloadable)**
- **Inlet air filter for air quality control**

Power Options

- **Available in single-phase or three-phase configurations**
- **240 Volt, 125 Amp single-phase circuit or 240 Volt, 80 Amp 3-phase circuit**
- **Circuit breaker load center included (based on configuration)**

Shipping & Setup

- **Ships fully assembled**
- **Built-in lift points for easy transport and installation**
- **Made and designed in the USA**

THE SCHUTTE HAMMERMILL MINI MILL

The operational capability of larger
equipment at a fraction of the price

Schutte Hammermill is bringing its reputation for tough, rugged construction to our smallest unit yet

The Schutte Hammermill Mini Mill offers the some operational capability of larger size reduction equipment at the fraction of the price. This completely portable unit plugs into a standard wall outlet.

Options for food grade, stainless and carbon construction make the Mini Mill ideal for a wide variety of applications. With minimal changes, the Mini Mill can be configured to suit the user's production goals and produce an end-result with consistent, uniform bulk-density and particle size distribution.



Mill top hinges opens for easy maintenance

Applications

- Herbs and Spices
- Cannabis
- De-Agglomeration of Chemicals and Powders
- Small Batch Processing
- Analytical Testing
- University and Government Testing Facilities

Key Features

- Plugs into standard 110V - 120V outlet
- Optional Variable Frequency Drive
- Optional pneumatic air-assist
- Standard safety interlock switch
- Hinged mill top opens for easy maintenance

Appendix A. Screw Press, Dryer, and Mill Product Sheets Continued

Technical Specifications

Model	Feed Opening	Footprint	Power
MM-4	4" x 4"	18.5" x 20" (470 x 508 mm)	¾ hp (0.6 kw)
MM-12	4" x 12"	18.5" x 37" (470 x 940 mm)	3 hp (2 kw)
MM-16	6" x 16"	33" x 45" (838 x 1143 mm)	5 hp (3.7kw)



Backed by the Schutte Hammermill Reputation

With thousands of installations around the world, and nearly a century's worth of experience, Schutte Hammermill has a solution for your size reduction challenge. We offer over 200 sizes and styles of mills, and can provide the perfect size machine for each customer's specific processing rate requirements. Call us today to find out more about how we can help improve your process. Call 800/447-4634 or visit www.hammermills.com for more information on the full line of size reduction equipment made by Schutte Hammermill

Kodiak Archipelago Leadership Institute's Alutiiq Grown Dried Sugar Kelp (*Saccharina latissima*)



Ingredients

Dried Sugar Kelp (*Saccharina latissima*)

Product Description

0.5 lbs. Dried Sugar Kelp, free flowing
Powder <10% moisture, food grade

Shelf Life

2 years unopened, 6 months once
opened

Storage Conditions

Store between 45-70 F, avoid moisture
and direct sunlight. Close zip top
seal on bag completely

Allergens*

Product of the Sea, may contain
trace amounts of fish and
shellfish

Packaging

Packaged in an aluminum lined
zip top closure, resealable bags
with a food grade desiccate pack
to ensure freshness



* All products tested by a
certified lab for nutritional
analysis, allergens, and
microbial safety. Testing
results available upon
request.



Nutrition Facts

62 servings per container
Serving size 1 tsp (3.65g)

Amount per serving
Calories 10

	% Daily Value*
Total Fat 0g	0%
Saturated Fat 0g	0%
Trans Fat 0g	
Cholesterol 0mg	0%
Sodium 125mg	5%
Total Carbohydrate 1g	0%
Dietary Fiber 1g	4%
Total Sugars 0g	
Includes 0g Added Sugars	0%
Protein 1g	
Vitamin D 0mcg	0%
Calcium 50mg	4%
Iron 0.6mg	4%
Potassium 550mg	10%
Iodine 14381mcg	9590%

*The % Daily Value tells you how much a nutrient in a
serving of food contributes to a daily diet. 2,000 calories a
day is used for general nutrition advice.

Kodiak Archipelago Leadership Institute's Alutiiq Grown Dried Bull Kelp (*Nereocystis luetkeana*)



Ingredients

Dried Bull Kelp (*Nereocystis luetkeana*)

Product Description

0.5 lbs. Dried Bull Kelp, free flowing
Powder <10% moisture, food grade

Shelf Life

2 years unopened, 6 months once
opened

Storage Conditions

Store between 45-70 F, avoid moisture
and direct sunlight. Close zip top
seal on bag completely

Allergens*

Product of the Sea, may contain
trace amounts of fish and
shellfish

Packaging

Packaged in an aluminum lined
zip top closure, resealable bags
with a food grade desiccate pack
to ensure freshness



* All products tested by a
certified lab for nutritional
analysis, allergens, and
microbial safety. Testing
results available upon
request.



Nutrition Facts	
62 servings per container	
Serving size	1 tsp (3.65g)
Amount per serving	
Calories	10
	% Daily Value*
Total Fat 0g	0%
Saturated Fat 0g	0%
Trans Fat 0g	
Cholesterol 0mg	0%
Sodium 200mg	9%
Total Carbohydrate 1g	0%
Dietary Fiber 1g	4%
Total Sugars 0g	
Includes 0g Added Sugars	0%
Protein 1g	
Vitamin D 0mcg	0%
Calcium 20mg	2%
Iron 0.7mg	4%
Potassium 500mg	10%
Iodine 4855mcg	3240%
*The % Daily Value tells you how much a nutrient in a serving of food contributes to a daily diet. 2,000 calories a day is used for general nutrition advice.	

Appendix B. Dried and Milled Kelp Product Specification Sheets Continued

Kodiak Archipelago Leadership Institute's Alutiiq Grown Dried Dragon Kelp (*Eualaria fistulosa*)



Ingredients

Dried Dragon Kelp (*Eualaria fistulosa*)

Product Description

0.5 lbs. Dried Dragon Kelp, free flowing
Powder <10% moisture, food grade

Shelf Life

2 years unopened, 6 months once
opened

Storage Conditions

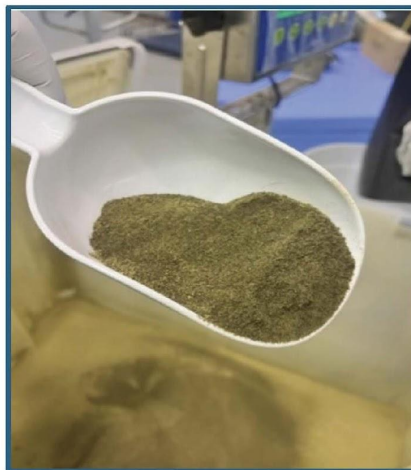
Store between 45-70 F, avoid moisture
and direct sunlight. Close zip top
seal on bag completely

Allergens*

Product of the Sea, may contain
trace amounts of fish and
shellfish

Packaging

Packaged in an aluminum lined
zip top closure, resealable bags
with a food grade desiccate pack
to ensure freshness



* All products tested by a
certified lab for nutritional
analysis, allergens, and
microbial safety. Testing
results available upon
request.



Nutrition Facts	
62 servings per container	
Serving size	1 tsp (3.65g)
Amount per serving	
Calories	10
	% Daily Value*
Total Fat 0g	0%
Saturated Fat 0g	0%
Trans Fat 0g	
Cholesterol 0mg	0%
Sodium 85mg	4%
Total Carbohydrate 2g	1%
Dietary Fiber 2g	7%
Total Sugars 0g	
Includes 0g Added Sugars	0%
Protein 1g	
Vitamin D 0mcg	0%
Calcium 40mg	4%
Iron 0.1mg	0%
Potassium 240mg	6%
Iodine 1234mcg	820%

*The % Daily Value tells you how much a nutrient in a serving of food contributes to a daily diet. 2,000 calories a day is used for general nutrition advice.