Development of a Method to Produce Freeze-Dried Cubes from 3 Pacific Salmon Species

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Abstract: Freeze-dried boneless skinless cubes of pink (Oncorhynchus gorbuscha), sockeye (Oncorhynchus nerka), and chum (Oncorhynchus keta) salmon were prepared and physical properties evaluated. To minimize freeze-drying time, the kinetics of dehydration and processing yields were investigated. The physical characteristics of the final product including bulk density, shrinkage, hardness, color, and rehydration kinetics were determined. Results showed that freeze-dried salmon cubes from each of the 3 Pacific salmon species can be produced with a moisture content of less than 10% and a w < 0.4 and freeze-drying time of 9 h. Processing yields ranged from 26% to 28.4%, depending on fish species. Shrinkage was less than 12% and rehydration of freeze-dried cubes was rapid. The value-added products developed have the potential to be utilized as ingredients for ready-to-eat soups, as snack food, salad topping, and baby finger-food.

Keywords: dried fish, fish muscle, freeze-dried food, Pacific salmon

Practical Application: Freeze-drying removes water from food products without heating them; therefore, this type of drying process yields very high-quality dried foods. In this study, a freeze-dry process was established to produce small cubes of Alaska pink, sockeye, and chum salmon. The goals were to shorten typical freeze-drying time while producing acceptable product characteristics. The freeze-drying process developed took only 9 h to remove about 97% of the moisture of diced Pacific salmon fillets. The freeze-dried salmon cubes produced can be used as ingredients for dehydrated ready-to-eat soups, as baby finger-foods, or as salad toppings.

Introduction

In 2008, the total catch for the 5 Pacific salmon species in Alaska was 321054969 kg. The estimated value for the Alaska Pacific salmon fisheries has increased significantly from 2006 to 2008, rising from $346 to $452 million. The global demand for products from wild caught Pacific salmon is increasing and the opportunity exists for the development of value-added products from these species.

Drying is an old preservation process. Conventional drying produces dehydrated products that can have an extended shelf life of up to 1 yr; however, quality of the final product is often reduced as compared to that of the raw material (Ratti 2001). Freeze-drying is an alternative drying process that has the advantages of maintaining material structure while removing moisture at low temperature, increasing product stability during storage, and minimizing degradation reactions (Ratti 2001; Boss and others 2004; Krokida and Philippopoulos 2006). Freeze-drying is based on sublimation, where water is removed directly from solid state to vapor phase.

Due to the absence of liquid water and low operating temperatures and pressures, product deterioration and microbiological activity are kept to a minimum during processing (Hammami and others 1999). Freeze-drying protects the primary structure and the shape of the food product because water is removed by sublimation, resulting in minimal reduction of volume (Ratti 2001). However, disadvantages of freeze-drying are the high energy requirements, and long processing times. This leads to high production costs that force the retail price of freeze-dried products to be high. Despite this, global demand for freeze-dried products is increasing because products are of excellent quality (Genni and others 1996). These products are made as snacks, finger foods, salad toppings, dehydrated soup ingredients, and military and space food among others. Seafood plays a small, but valuable role in the freeze-dried foods market with shrimp being one of the most recognizable products followed by clams, crab, lobster, and octopus. Interestingly, despite the fact that fishery products account for a significant portion of the human food supply, freeze-dried foods produced from fish have limited supply availability worldwide.

The objective of this study was to develop a method for producing freeze-dried fish cubes using the 3 most abundantly harvested Pacific salmon species in Alaska, pink (Oncorhynchus gorbuscha) (PS), sockeye (Oncorhynchus nerka) (SS), and chum salmon (Oncorhynchus keta) (CS). To achieve this goal, freeze-drying processing parameters were studied and possible species-specific differences influencing the process were determined. Moisture content below 10% is optimal for freeze-dried products to obtain satisfactory reversible compression properties, which is a requirement for products to have sufficient plasticity (MacKenzie and Luyet 1969; Booh-Occamey 1984; Ratti 2001). Methods of achieving low moisture content in freeze-dried products have been previously discussed (King and others 1976; Zarkarian and King 1978; Booh-Occamey 1984; Ratti 2001). On the whole, the most critical
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parameter for a freeze-drying process to be economically feasible is drying time, because it is the determinant variable to establish energy costs. Therefore, our experimental design was based on reaching 2 main objectives: the product having moisture content below 10%, and the drying time as short as possible (Boss and others 2004). Upon establishing optimal processing conditions, several quality parameters for each of the 3 final products were measured and compared with regard to species-specific differences.

Materials and Methods

Sample procurement and preparation

In August of 2008, 70 whole fresh grade A Pacific salmon were purchased from a local seafood processor in Kodiak, Alaska. All fish were procured from the same fishing vessel and were less than 48 h post-mortem. A total of 30 pink salmon, 20 sockeye salmon, and 20 chum salmon were procured. Fish were hand filleted with skin, pin bones, and dark muscle removed. Fillets were vacuum packaged in 4 mm polypropylene bags, frozen in a blast freezer at −40 °C, and stored at −30 °C until freeze-dried.

Freeze-dry process

Total of 9 preliminary trials were conducted to establish adequate freeze-drying (FD) parameters. Preliminary FD trials were conducted using pink salmon (Table 1). Each of the 9 trials was conducted once using an average of 3 pink salmon fillets, randomly sampled from the 60 pink salmon fillets. The frozen fillets were partially thawed, and cut into cubes of approximately 5 × 5 × 5 (±1) mm using a filleting knife. Cutting was performed in a cool room (5 °C) to prevent fillets from thawing. Semi-frozen cubes were arranged into freeze-dry trays (25.5 × 51 × 3.8 mm) and processed immediately. Moisture content and water activity were determined at the end of each trial and process variables were adjusted in subsequent trials (Table 1). After choosing the FD conditions that yielded pink salmon FD cubes with moisture content at about 10% and aw below 0.4 (Trial 7, Table 1). The processing conditions described for Trial 7 were used for each salmon species (red, pink, and chum) and repeated 3 times, using process duration times of 5.5, 7, 8, 8.5, and 9 h. This signifies that Trial 7 was stopped prematurely for process duration times from 5.5 to 8.5 h. Trials 4 and 6 were used to determine data points at 9.5 and 11 h of processing time. There were a total of 15 FD runs using the FD conditions described in Trial 7 (Table 1), and 3 additional runs for Trials 4 and 6 for a total of 21 runs for each species. Therefore, during the course of this study, and after the preliminary study was concluded, FD Trial 7 was conducted 45 times while Trials 4 and 6 were conducted 18 times each, for a total of 63 FD runs. Each run used an average of 4 to 5 fillets from each salmon species cut into cubes. The hand cut semifrozen salmon cubes produced from each of the 3 species (PS, SS, and CS) were FD using a Virtis Freeze Drier (Model 52 ES, Gardner, N.Y., U.S.A.). Moisture content and water activity of the FD cubes of each species were immediately measured at the end of drying process.

Proximate composition

Proximate composition of unprocessed (raw) pink, sockeye, and chum salmon cubes was determined in triplicate from pooled fillet samples that were used through out the study. Moisture content was measured gravimetrically by drying samples for 24 h at 102 °C using AOAC method nr 952.08 (Helrich 1990). Ash content was determined gravimetrically by placing samples into a muffle furnace at 550 °C for 24 h using AOAC method nr 938.08 (Helrich 1990). Protein was measured using a LECO protein analyzer (Model FP 2000, LECO, St. Joseph, Mich., U.S.A.). The nitrogen content was quantified and protein content was calculated from nitrogen content times 6.25. Lipid was measured using method as described by Folch and others (1957).

Water activity

Water activity was determined using an AquaLab Series 3 TE (Decagon Devices Inc., Pullman, Wash., U.S.A.). Triplicate measurements were conducted for each sample and results averaged for each sample. Results were expressed as sample means ± SD.

Dehydration kinetics

Dehydration kinetics were measured by running each freeze-dried process trial for 5.5, 7, 8, 8.5, 9, 9.5, and 11 h. A total of 21 freeze-drying trials were conducted for each fish species to determine the dehydration kinetics for optimal freeze-drying. A relationship between moisture content (MC) and drying time was

Table 1—Experimental conditions for freeze-drying pink salmon cubes (5 × 5 × 5 mm) where the condenser temperature was −35 °C and chamber pressure was 5.33 Pa for all trials.

<table>
<thead>
<tr>
<th>Freezing step (shelf T against t)</th>
<th>Primary drying step (shelf T against t)</th>
<th>Secondary drying step (shelf T against t)</th>
<th>Total process (h)</th>
<th>Moisture (%)</th>
<th>Water activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 2 h at −30 °C</td>
<td>18 h at −40 °C</td>
<td>2 h at 45 °C</td>
<td>22</td>
<td>2.6</td>
<td>&lt;0.03</td>
</tr>
<tr>
<td>2 2 h at −30 °C</td>
<td>14 h at −40 °C</td>
<td>2 h at 30 °C</td>
<td>18</td>
<td>3.2</td>
<td>&lt;0.03</td>
</tr>
<tr>
<td>3 0.5 h at −30 °C 1.5 h at −40 °C</td>
<td>2 h at −40 °C 2 h at −30 °C 2 h at</td>
<td>2 h at 25 °C</td>
<td>14</td>
<td>3.7</td>
<td>0.05</td>
</tr>
<tr>
<td>4 0.5 h at −30 °C 1.5 h at −40 °C</td>
<td>2 h at −40 °C 2 h at −30 °C 1.5 h at</td>
<td>1 h at 25 °C</td>
<td>11</td>
<td>4.1</td>
<td>0.08</td>
</tr>
<tr>
<td>5 0.5 h at −30 °C 1.5 h at −40 °C</td>
<td>2 h at −40 °C 1.5 h at −30 °C 1.5 h at</td>
<td>1 h at 25 °C</td>
<td>10.5</td>
<td>5.5</td>
<td>0.10</td>
</tr>
<tr>
<td>6 0.5 h at −30 °C 1 h at −40 °C</td>
<td>2 h at −40 °C 2 h at −30 °C 1.5 h at</td>
<td>1 h at 25 °C</td>
<td>9.5</td>
<td>5.9</td>
<td>0.14</td>
</tr>
<tr>
<td>7 0.5 h at −30 °C 1 h at −40 °C</td>
<td>2 h at −40 °C 2 h at −30 °C 1.5 h at</td>
<td>0.5 h at 25 °C</td>
<td>9</td>
<td>8.5</td>
<td>0.35</td>
</tr>
<tr>
<td>8 0.5 h at −30 °C 1 h at −40 °C</td>
<td>2 h at −40 °C 2 h at −30 °C 1.5 h at</td>
<td>0 h at 25 °C</td>
<td>8.5</td>
<td>10.8</td>
<td>0.52</td>
</tr>
<tr>
<td>9 0.5 h at −30 °C 1 h at −40 °C</td>
<td>2 h at −40 °C 2 h at −30 °C 1.5 h at</td>
<td>0 h at 25 °C</td>
<td>8</td>
<td>16.8</td>
<td>0.67</td>
</tr>
</tbody>
</table>

T = temperature; t = time.
established. Kinetics of dehydration was described by a curve of MC versus drying time. The dehydration coefficient (DC) was determined as the ratio between the quantities of removal water during drying time to initial water content according to formula as follows (Meda and Ratti 2005):

$$DC(\%) = \frac{W_0 - W_f}{W_0 - W_i} \times 100$$

where $W_0$, $W_f$, and $W_i$ are the initial weight of sample, its weight after drying, and its dry mass, respectively.

**Processing yields**

Process yield was determined in triplicate by weighing samples before and after freeze-drying. The yields were calculated according to formula below:

$$Yield(\%) = \frac{W_c}{W_s} \times 100$$

where $W_c$ and $W_s$ are weight of sample after and before drying, respectively.

**Apparent density and volumetric shrinkage**

Apparent density (AD) was measured using a displacement method (Rao and others 2005) for each salmon cube at specific processing times (5.5, 7, 8, 8.5, 9, 9.5, and 11 h). Samples were immersed into a toluene solution in a volumetric cylinder with a precision of $10^{-1}$ mL. Volumetric changes were recorded and AD was calculated as the ratio of sample weight per its volume (kg/m³) (Khaliloufi and Ratti 2003). Volumetric shrinkage (VS) was determined according to the formula shown subsequently adapted from Boeh-Ocansey (1984) to report results as percent shrinkage (Khaliloufi and Ratti 2003):

$$VS(\%) = \frac{V_0 - V_f}{V_0} \times 100$$

where $V_0$ and $V_f$ are volume of sample after and before drying, respectively. Sample volume was determined using an Electric Digital Caliper (Max-Cal, Fowler & NSK Co., Tokyo, Japan) with a precision of $10^{-2}$ mm. Sample volume was determined as the average of readings taken from 15 individual cubes per species.

**Textural changes**

Textural changes during freeze-drying were determined for each salmon cube at specific processing times (5.5, 7, 8, 8.5, 9, 9.5, and 11 h). Texture was measured using a Texture Analyzer (Model TA-HDi, Stable Micro Systems Ltd., Surrey, U.K.) equipped with a load cell of 5 kg and a 25 mm φ cylinder probe (Stable Micro Systems Ltd.). Results were expressed as maximum deformation force (MDF) (Texture Technologies 2002). The traveling speed of the cylinder was 2 mm/s. The force-time graphs were recorded using the Texture Expert Exceed software for Windows XP (Stable Micro Systems Ltd.). The hardness value was measured as the peak force height, which was calculated from texture profile analysis (TPA) curve (Bourne 1978). Total of 20 cubes for each trial were tested. Results were expressed as mean ± standard deviation (SD) and reported as MDF per sample weight (g/g).

**Color changes**

Color changes during freeze-drying were determined for the cubes after 5.5, 7, 8, 8.5, 9, 9.5, and 11 h processing. Color was determined using a Minolta colorimeter (Model CR-300, Minolta Co. Ltd, Osaka, Japan). Tests were carried out in triplicate using 5 g of FD cubes for each of the processing times. An average reading was calculated from measuring 5 different locations in each sample. Color were expressed as $L^*$ (whiteness), $a^*$ (redness), and $b^*$ value (yellowness), according to the recommendation of the Intl. Commission on Illumination (CIE 1978). Before measuring color the colorimeter was calibrated using a white calibration plate.

**Rehydration time**

Time of rehydration was conducted for FD cubes freeze-dried for 9 h using a Precision thermostatic bath model 25 (Precision Scientific, Chicago, Ill., U.S.A.) operated at 80 °C. This rehydration temperature was chosen because our goal was to produce products that would be used in dried soup mixes. Approximately 3 g of sample were completely immersed in 500 mL distilled water with samples removed every 2 s to measure the ratio of water uptake. After the rehydration and before weighing, the samples were drained for 5 min. Rehydration ratio (RR) was calculated using the following equation (Narasimham and John 1995):

$$RR(\%) = \frac{W_{re} - W_{br}}{W_{br}} \times 100$$

where $W_{re}$ and $W_{br}$ are weight of sample after and before the rehydration, respectively. Each experiment was performed in triplicate and results expressed as mean ± SD.

**Statistical analysis**

Results were statistically analyzed to determine differences between the 3 salmon species with regards to processing variables and physical and chemical properties of the freeze-dried products. Data was subjected to analysis of variance (ANOVA) followed by Tukey’s HSD test ($P < 0.05$) to determine differences using Statistica version 9.0 (Statsoft, Tulsa, Okla., U.S.A.).

**Results and Discussion**

**Proximate composition**

Proximate composition was significantly ($P < 0.05$) different in moisture, lipid, and protein between the 3 species of Pacific salmon. Moisture content for PS, CS, and SS fillets was 76% ± 0.2%, 73.3% ± 0.1%, and 71.5% ± 0.1%, respectively. Lipid content was markedly different between species with PS having 0.53% ± 0.05%, while CS had 0.92% ± 0.05% and SS had higher lipid content at 1.38% ± 0.02%. Protein content was 22.25% ± 0.12% for PS, 24.45% ± 0.04% for CS, and 25.80% ± 0.04% for SS. Ash values ranged from 1.18% ± 0.17% to 1.38% ± 0.07%, and did not significantly differ between species. This difference is typical of Pacific salmon with PS considered the leanest species and SS as having higher fat content.

**Freeze-drying process**

Results obtained from 9 freeze-drying trials for pink salmon cubes are shown in Table 1. The objective of these trials was to find the time and temperature process that would produce FD cubes with less than 10% moisture and an $a_*$ not greater than 0.4. These targets were suggested by others (Ratti 2001; Eikevik and others 2005). Trials 1, 2, and 3 proved useful in developing the combinations of time and temperature effective in decreasing FD time. Product produced during these trials had extremely low
moisture and $a_w$ values, but provided limits for developing the optimum FD procedure. Small adjustments in the primary drying step were performed in Trials 4, 5, and 6, and again a decrease in processing time was observed. Times at the end of the process were shortened as it appeared the bulk of the moisture was being removed in the first 5.5 h and these adjustments were the fine tuning needed to achieve target values. The FD product from Trial 6 had a moisture content of 5.9%, which was below the 10% target. Finally adjustments in the secondary drying steps (Trials 7 and 8) produced a product with moisture content of 8.5% and 10%. The secondary drying process at 25 °C was critical to achieving the desired water activity and moisture content. Trial 7 was chosen as the drying process for all subsequent FD products.

Dehydration kinetics, water activity, and processing yield

Drying kinetics is generally the most important datum required for the design of drying processes. Although essential information can be obtained through lab-scale experiments all the necessary data under different operating conditions is not usually available (Ratti 2001). During the first 7 h of the freeze-drying process, dehydration took place quickly, resulting in a significant decrease ($P < 0.05$) in the moisture content (MC; Figure 1). At 7 h, about 80% of the moisture had been removed from all samples. After 8.5 h of drying water sublimation occurred in a much slower rate and there were no significant differences ($P > 0.05$) in MC between species. There was little benefit in continuing the FD process beyond 8.5 h. With regards to species-specific differences during FD, it was noted that drying curves were different for the first 8 h of processing ($P < 0.05$). The PS cubes had the greatest amount of water removed, followed by SS and CS (Figure 1). This result reflects the proximate composition of the raw materials, where PS had the highest moisture content. Eikevik and others (2005) reported that freeze-drying of cod fish cubes (5 × 5 × 5 mm), at atmospheric condition with a plate temperature of −8 °C and post drying temperature of 20 °C, took approximately 9.2 h to reach moisture content below 10%.

Water activity decreased with increased in FD time (Figure 2). Pink salmon cubes exhibited the most rapid decrease in water activity as compared to sockeye or chum salmon. This again relates to the higher moisture content of raw pink salmon. At 9 h the $a_w$ of FD salmon cubes, regardless of species, were below 0.4. The decrease in $a_w$ between 8 and 9 h was the critical factor since lower water activity often improves storage life of dried foods. Nonenzymatic browning (Maillard reaction) has a pronounced maximum at $a_w$ between 0.5 and 0.7 (Warmhier and others 1976). Other chemical and enzymatic reactions can occur in dried foods containing lipids even at water activity below 0.6, which results in loss of product quality (Labuza and others 1972).

After completion of the primary drying stage at 8.5 h, DC reached 96.2%, 97%, and 96.3% for PS, SS, and CS, respectively. During secondary drying and up to 11 h of processing DC further increased to about 98%, regardless of fish species. In general, freeze-dried foods have 98% of their initial water removed, and this reduces the food’s weight by about 90%. In our study, similar water content reduction has been observed.

As expected, freeze-drying yields for PS, CS, and SS cubes was a function of process duration (Figure 3). As a general rule, the FD yield decreases with increasing drying times. During the first 8.5 h of the FD process rapid dehydration occurs, thus a sharp decrease in processing yield is observed. At 8.5 h of drying, the yields for

Figure 1–Kinetics of dehydration during freeze-drying of salmon cubes. Where PS = pink salmon; SS = sockeye salmon; CS = chum salmon; Point = Mean; Whiskers = Standard error of the mean. Freeze drying parameters are those of Trials 4, 6, and 7 in Table 1.

Figure 2–Water activity of salmon cubes as a function of freeze-drying time. Where PS = pink salmon; SS = sockeye salmon; CS = chum salmon; Point = Mean; Whiskers = Standard error of the mean. Freeze drying parameters are those of Trials 4, 6, and 7 in Table 1.

Figure 3–Processing yield for salmon cubes as a function of freeze-drying time. Where PS = pink salmon; SS = sockeye salmon; CS = chum salmon; Point = Mean; Whiskers = Standard error of the mean. Freeze drying parameters are those of Trials 4, 6, and 7 in Table 1.

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PS, SS, and CS were 27.5%, 30.5%, and 27.5%, respectively. No differences (P > 0.05) in yields were observed for PS and CS after 8.5 h of drying. SS has the highest recovery because it has the lowest moisture content. One of the requirements for successful application of freeze-drying to Pacific salmon will be to optimize processing yield while maintaining the appropriate water activity and moisture content.

Bulk density and volumetric shrinkage

Results indicated that AD decreased significantly during drying process (P < 0.05) for all species (Figure 4). Apparent density (AD) for the different species was also significantly different (P < 0.05). A 2-fold reduction in AD was observed for SS with values decreasing from 1060 (raw) to 560 (FD) (kg/m³). For PS the AD reduction was less than 2-fold with values decreasing from 1100 (raw) to 740 (FD) (kg/m³). For CS the AD reduction was very similar to PS with values decreasing from 1050 (raw) to 690 (FD) (kg/m³). A correlation between AD and lipid content may exist with higher lipid content in the raw material leading to lower AD in the freeze-dried product. Khaliloufi and Ratti (2003) determined the bulk density (kg/m³) of freeze-dried strawberries, apples, and pears and values ranged from 97 to 162 while in colloidal 800 kg/m³ observed in Figure 4 for AD of the 3 FD Pacific higher than that of FD fruits, and this reflects the range of 550 thus, the apparent density of FD Pacific salmon should be much lower AD for the different species was also significantly different (P < 0.05). A correlation between AD and lipid content may exist with higher lipid content in the raw material leading to lower AD in the freeze-dried product. Khaliloufi and Ratti (2003) determined the bulk density (kg/m³) of freeze-dried strawberries, apples, and pears and values ranged from 97 to 162 while in colloidal 800 kg/m³ observed in Figure 4 for AD of the 3 FD Pacific salmon products.

The volumetric shrinkage (VS) of the products at 9 h of drying, and the values for PS, SS, and CS averaged 10.5%, 9.4%, and 11.9%, respectively (Table 2). No significant difference in VS was noted among species (P > 0.05) and the shrinkage ratios are in agreement with values reported for other freeze-dried products. Boeh-Ocansey (1984) reported that freeze-drying carrots under vacuum conditions (pressure of 0.3 mmHg or 40 Pa, using a freeze drier SERIAL RP3V) resulted in a volumetric shrinkage of 44%, which is much higher than the values determined in our study. On the other hand, Khaliloufi and Ratti (2003) determined that the shrinkage volume of freeze-dried apples and strawberries were approximately 13% and 8%, respectively. These results are similar to the 9% to 12% shrinkage values for FD salmon products.

Textural and color changes

Hardness of salmon cubes peaked at different drying times according to species. For PS the initial hardness value was 43 g/g (raw), and peaked to 5504 g/g at 9 h. For CS the initial hardness measured was 57 g/g (raw), but hardness peaked to 4561 g/g at 9 h of drying, while for SS hardness only peaked at 11 h of drying, raising from 54 g/g for raw product to 3799 g/g (Figure 5). Reidy and Heldman (1970) reported that for freeze-dried beef, hardness, and chewiness values were highest at water activities between 0.4 and 0.6, thus the increase in hardness is clearly related to water elimination during FD. It can be noted in Figure 6 that a slight decrease in hardness values for PS and CS occurred at the end of the drying process; however, additional research must be carried out to explain this observation.

Significant color changes occurred during drying (Figure 6). Overall SS had the highest a∗ and b∗ values, followed by PS and CS (Figure 6, panels B and C). In contrast, PS had the highest L∗ values, followed by SS then PS (Figure 6, panel A). L∗ values increased with increasing drying times, regardless of species, while a∗ values and b∗ values decreased. As expected, a∗ and b∗ values of SS FD cubes were significantly higher than PS and CS (P < 0.05), due to the natural bright red color of the sockeye salmon fillets. Overall, the increase in L∗ value is thought to be a result of dehydration, while the observed decrease in a∗ value during FD is possibly due to oxidation of naturally occurring pigments in salmon muscle such as astaxanthin and cathaxanthin. Observed L∗a∗b∗ value changes agree with the color changes reported for freeze-dried cod fish (Eikevik and others 2005). Other researchers have recorded loss of naturally occurring pigment in FD seafood products such as shrimp and salmon (Lusk and others 1964;
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Martinez and Labuza (1968) and in FD apples (Krokida and Philipopoulos 2006); and their findings support our observations regarding color changes in FD Pacific salmon.

Rehydration time

Rehydration was carried out at 80 °C to research the time the products would take to absorb water in case these were used as ingredients to dry soup mixes. FD salmon cubes, regardless of species, rehydrated very quickly, reaching a maximum value of water uptake in only a few seconds (Figure 7). The PS cubes showed the highest rehydration ratio of 166% in 4 s, the CS cubes rehydrated to 175% in 8 s, while SS cubes rehydration ratio was 126% after 10 s. Quick rehydration rates are not surprising due to the porous texture of the material. This rapid rehydration may pose a problem for these products as it also indicates the cubes may dissolve into solution and provide no textural component to the food. Further investigation is needed to determine textural integrity as a rehydrated product.

Conclusions

A freeze-dry process was established for cubes from Alaska pink, sockeye, and chum salmon. The goals were to shorten typical freeze-drying time while producing acceptable product characteristics. The FD process developed resulted in the production of FD cubes with moisture content below 10% and \( a_w \) below 0.4, when freeze-dried for 9 h. This time was much shorter than traditional processes that can take as long as 48 h. The processing yields were species-specific ranging from 26% to 28.4%. This is an acceptable recovery for FD foods and can be further optimized by carefully monitoring the processing method. The color of the FD product was typical of Pacific salmon although slightly lighter in appearance as characterized by increased \( L^* \) values and decreased \( a^* \) and \( b^* \) values. Product shrinkage was less than 12% indicating the FD process did not change shape very much. There was a fast rate of rehydration, a desirable property for using FD salmon in dry soup formulations, although the rapid time may also indicate the product dissolves and does not provide needed texture. These product characteristics suggest FD salmon cubes could be used as ingredients for dehydrated ready-to-eat soups, as baby finger-foods, or as salad toppings. Additional research is needed to determine the nutritional values of the products and their oxidative stabilities, to develop a system to incorporate flavoring agents to the FD salmon cubes, and to conduct storage stability trials using different packaging systems.

Acknowledgments

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Figure 6—Panel A is change in \( L^* \) value of salmon cubes during the freeze-drying process. Panel B is change in \( a^* \) value of salmon cubes during the freeze-drying process. Panel C is change in \( b^* \) value of salmon cubes during the freeze-drying process. Where PS = pink salmon; SS = sockeye salmon; CS = chum salmon; Point = Mean; Whiskers = Standard error of the mean. Freeze drying parameters are those of Trials 4, 6, and 7 in Table 1.

Figure 7—Rehydration time of freeze-dried salmon cubes at 80 °C. Where PS = pink salmon; SS = sockeye salmon; CS = chum salmon; Point = Mean; Whiskers = Standard error of the mean. Freeze drying parameters are those of Trials 4, 6, and 7 in Table 1.
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References