Combined electrohydrodynamic (EHD) and vacuum freeze drying of shrimp

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Abstract. To improve the drying qualities of shrimp, a combination of electrohydrodynamic (EHD) and vacuum freeze drying (FD) is examined. The drying rate, the shrinkage, the rehydration ratio, and the sensory properties including the color and trimness of the dried products under different drying methods (including combination drying of EHD and FD, EHD drying and FD drying) are measured. Compared with FD and EHD drying alone, the combined process consumes less drying time, and the product processed by combined drying displays lower shrinkage, higher rehydration rate and better sensory qualities.

1. Introduction
Shrimp and fish represent one major source of protein to human beings in the world. Their preservation is an important issue because they are perishable products. Drying has been proved to be an efficient and cheap method for food preservation [1-4]. It has been used to preserve fish and shrimp for a long time in most areas of the world.

At present, the conventional drying processes of shrimp include solar drying and hot air drying. The latter often causes heat damage and adversely affects texture, color, flavor, and the nutritional value of dried products [5]. Although solar drying does not need special equipment and technology, and neither does it incur high expenses, its drying conditions are difficult to control. As a result, the product quality is often poor [6].

To improve their preservation quality and consumer acceptability, new drying technology for shrimp is needed. It is widely known that although FD is an excellent drying method from quality standpoint, its energy consumption is excessive compared with other methods of drying. It is, therefore, desirable to evaluate new drying technologies to achieve better product quality and more reasonable cost.

As mentioned by Mujumdar, agricultural and food products should be dried by efficient industry equipment so how to select a proper dehydration method should be considered firstly [7]. Consideration should be given to many factors before selecting a drying process. These factors are the type of product to be dried, the product's susceptibility to heat, pretreatments required, and capital and processing cost. There is no one best technique for all products [8]. For shrimp, the drying method should have properties of low temperature and high efficiency. There have been reports about heat...
pumps and solar tunnels used to dry fish [9, 10]. Hybrid drying methods are also important according to recent research results [11].

Combination drying technology can combine advantages of various drying methods, and avoid the disadvantages of a single drying method. Until now, many reports about combination drying have been developed. For example, Fito used five different combination drying methods (hot air-microwave, osmosis-hot air, vacuum osmosis-hot air, and vacuum osmosis-hot air-microwave) to dry banana and found that vacuum osmosis-hot air-microwave could improve its rehydration capability [12]. Bai et al. reported that a combination of freeze drying and electrohydrodynamic drying (EHD) could reduce drying time about 15% compared with freeze drying [13]. Xu et al also reported that convective air and vacuum freeze drying could get good product quality and relative short drying time during drying bamboo shoots [14]. FD technology also could be combined with heat pump or other drying methods; even atmospheric freeze drying (AFD) was developed to reduce power consumption [15].

From these research findings, FD could be combined with other drying methods conveniently for its own advantages. At present, there are no reports on drying shrimp using combination drying of EHD-FD (EHFD). The objective of this article is to examine the effect of three drying methods on rehydration and shrinkage of shrimp, and furthermore, introduce a new combination drying technology to improve dry shrimp quality and reduce drying time.

2. Materials and Methods

2.1. Preparation and drying of shrimps
Shrimps were procured from the local market. Before drying, shrimps were peeled and washed with tap water and were dipped in NaCl solution (8% w/v) at 90-99 °C for 10 min. They were then taken out and drained.

The samples were divided into three groups at random with similar weight in each group. Initial weights of the samples were measured by a digital balance. One group was subjected to EHD drying at 18±1°C. One group underwent FD drying, and the other one for EFD drying. The samples were dried by EHD for 3h, and then dried to the final water content (12±1%) by FD. All samples were dehydrated until they reached the final moisture content (12±1%).

2.2. Determination of moisture
Moisture content was determined by the oven method. At regular time intervals during the drying processes samples were taken out and dried in the oven for 7-8 h at 105°C until constant weight. Weighing was performed on a digital balance, and then moisture content (w.b.) was calculated.

2.3. Shrinkage measurement
Shrinkage determination was made by manually measuring the sizes of dried shrimp samples obtained from different drying processes using a vernier caliper. The equivalent spherical diameter of each sample was then determined and compared. Ten samples were taken for measurement for each experimental condition. Shrinkage was calculated using the following equation:

\[
\text{Shrinkage} = \frac{Z_0 - Z_f}{Z_0},
\]

where \(Z_0\) and \(Z_f\) are the volume of each group of shrimps at the beginning and at the end of each drying experiment, respectively.

2.4. Rehydration ratio measurement
Rehydration ratio was determined by soaking 10.00 ± 0.01 g of dried shrimps on a dry weight basis in 100 ml distilled water at ambient conditions for up to 24 h. The soaked shrimps were blotted with a paper towel every 2 h to remove excess water. They were then weighed and placed back into the soaking water. Water absorption value was expressed in percentage and calculated as grams of water absorbed per 100 g of dried shrimps through the following formula.
Percentage water absorption $= \frac{m_f - m_0}{m_0} \times 100$  \hspace{1cm} (2)

where $m_0$ and $m_f$ are the weights of dry and soaked shrimps, respectively.

2.5. Sensory evaluation

A sensory evaluation of dried samples was carried out by a panel of six untrained judges. The panelists were asked to indicate their preference for each sample, based on the quality attributes of color, appearance, texture, aroma/flavor, and overall acceptability. A balanced 10-point hedonic rating was employed for all the attributes evaluated where 9-10 denoted “like very much” (7-8 “like,” 5-6 “neutral,” 3-4 “dislike”) and 1-2 indicated “dislike very much.” The judges were asked to give their remarks about each of the samples.

3. Results and discussion

3.1. Influence of different drying conditions on drying rate

As shown in figure 1, the drying rate of the FD technique was the slowest, followed by EHFD; EHD drying exhibited the fastest drying rate. The average drying rate for FD, EHFD, and EHD drying were 2.15, 2.85, and 3.25 g h$^{-1}$, respectively.

3.2. Influence of different drying conditions on shrinkage

During drying, foods undergo volume changes either by shrinkage (due to the removal of water from the drying shrimp) or by expansion (due to gas generation or pore formation). Different drying techniques thus provide different degrees of volume changes. Normally, the muscle fibers shrink as they lose moisture during the drying process. Figure 2 shows the results of shrinkage of shrimp that underwent different drying methods. Shrinkage was found to be lower for EHFD than for EHD. The final shrinkage values for FD and EHFD drying were 7.32% and 17.35%, respectively, while it was 23.40% for EHD drying. This shows that EHFD significantly reduces shrinkage.

![Figure 1](image1.png)  \hspace{1cm} ![Figure 2](image2.png)

**Figure 1.** Effect of different drying methods on average drying rate of shrimps.  \hspace{1cm} **Figure 2.** Effect of different drying methods on shrinkage ratio of shrimps.
3.3. Influence of different drying conditions on rehydration ratio
The rehydration characteristics of the dried product were used as a quality index because they could indicate the physical and chemical changes of samples during drying. The effect of the three drying methods on rehydration ratio is shown in figure 3. It shows that compared with EHD, the shrimp dried by EHFD had a good rehydration capability. The lower temperature used in FD drying might be the factor enabling EHFD-treated shrimp to hold more water compared with EHD-samples. The rapid evaporation of moisture in the shrimp induced a porous structure, which was in favor of the rehydration of products.

3.4. Influence of different drying conditions on sensory properties
As shown in figure 4. It can be seen that the total score of shrimp dried by FD was the highest followed by EHFD and EHD. FD could lead to the best quality, and EHFD could achieve a better quality.

4. Conclusions
Different drying methods such as EHD, FD, and EHFD had different effects on the quality and drying rate of the dehydrated shrimp. FD could lead to the best quality, but had the lowest drying rate. EHD shrimp had poor quality, and had a short drying time. Combination drying of EHFD could lead to better quality and drying efficiency.

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