Theses of Doctoral (PhD) Dissertation

POSSIBILITIES OF APPLYING DIFFERENT FOOD PRESERVATION PROCEDURES IN THE PRODUCTION OF PRESERVED FOODS

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1. Background and objectives of the doctoral thesis

Nowadays, the application of modern science in the military field has come to the fore. Military catering is a specialized set of complex systems where soldiers must be provided with the macro- and micronutrients required by their needs primarily through the food they consume, in addition to meeting specific requirements of military service such as edibility, shelf life and transportability.

The aim of my research is to design a process for preserving durable food, making the resulting product suitable for modern military use.

At the beginning of my research, I set the following objectives. The resulting food should be suitable for:

C1: It must have the proper nutritional content for Hungarian soldiers.

C2: It should be kept at a storage temperature of at least 45°C.

C3: It should have a quality retention period of at least 3 years.

C4: It should not take longer than 10 minutes to prepare for consumption.

C5: It should be suitable for military logistics requirements.

C6: The enjoyment value of the food should not significantly change.

C7: It should be suitable for battlefield catering.

Questions of research:

K1: Are the nutrient contents of commercially available foods adequate and acceptable in relation to those reported in available nutrient databases?

K2: Can the intentions of my objective be achieved using freeze drying technology?

K3: In the case of freeze-dried foods, can low-temperature rehydration, below 50°C and for less than 10 minutes, be achieved to restore the original texture and character of the food?

Hypotheses:

H1: The data reported in the international and national nutrient databases do not differ significantly from the nutrient and element content of commercially available raw materials.

H2: The use of freeze-drying technology ensures the physical, chemical, and microbiological stability of the finished product.

H3: The nutritional content and physical characteristics of foods have no effect on the quality of freeze-dried food.

H4: By using the right raw materials and preparation methods, the original texture and character of the food can be achieved during rehydration at low temperatures below 50°C and in less than 10 minutes.

Table 1: Hypotheses

Hypotheses		**Method used**	**Applied test**	**Number of objectives/ Research questions**
H1	The data published in the international and domestic nutrient database do not differ significantly from the nutrient and element content of the raw material from commercial circulation.	Analytical tests Statistical analysis	Nutrient tests Descriptive statistical analysis Normality test T-test Wilcoxon Test	C1, K1
H2	Using freeze-drying technology, the microbiological, chemical, and physical stability of the finished meal can be created.	Food stability testing	Water activity measurement. Acid number and peroxide number measurement	C2, C3, K2
H3	The nutritional content of foods and their physical characteristics have no influence on the quality of freeze-dried food.	Digital image analysis, Color measurement, Structural stability test	Nutrient content measurement Color measurement Software measurements of microscopic images Correlation analysis Principal component analysis	C5, K2
H4	With the use of appropriate raw materials and preparation methods, the original texture and character of the food can be achieved at low temperatures, below 50°C and during rehydration in less than 10 minutes.	Texture analysis Rehydration test Organoleptic examination	Shear force measurement using WBSF method. Rehydration at different temperatures and time. Regression analysis T-test	C4, C6, C7, K2, K3

The theoretical significance of my research is that I studied the rehydration of freeze-dried foods at low temperatures and in a relatively short time. Lyophilized ready meals are commercially available but require hot water and a duration of at least 20 minutes for rehydration. The food ingredients contained in them are either in powder form or relatively small in size, which does not reflect the true nature of the original food. However, the high energy requirements of rehydration, the longer duration, and the sensory difference due to the size differences of the creators do not allow military use. During my research, I examined food ingredients and preparation methods that make certain food suitable for shorter periods of rehydration at lower temperatures, while preserving the original character of the food.

The practical significance of the experiments is that with the raw materials, preparation methods and technological parameters proposed by me, freeze-dried food can be produced that is suitable for rehydration within 10 minutes at 40°C and its quality does not differ significantly from the original quality of the given food. As a long-term result of the research, the milestones achieved may contribute to the modernization of food on the battlefield and the production of possible new types of food packages, which overall supports the success of military operations. The experiments covered everything from the selection of raw materials and the method of preparation, through the determination of the applied technological parameters to the conditions of consumption.

An important quality, organoleptic characteristic is the stock of the product. of particular importance is the extent to which freeze-dried food recovers the texture or properties of the original food during rehydration. In various taste tests of freeze-dried foods in the middle of the last century, participants generally described meat-based rehydrated foods as "chewy," "fibrous," and "stringy," characterizing an inappropriate texture. Terms such as "watery or pasty" and "dry but leaking and soup" were also used, referring to inadequate rehydration (Bird 1963). Food has remained either over- or under-rehydrated (Moody 2019), so developing adequate rehydration and rehydration capabilities is the biggest technological challenge for freeze-dried foods.

2. Materials and methods

2.1. Materials

I examined medium-grained brown lenses, which I purchased in December 2021 with random, subjective selection in 500 g packages from the Hungarian market. The selection criterion was that the produce must have a different distributor or country of origin. I tested fifteen lenses from thirteen different distributors and two different countries. The potato samples were provided to me by dr. Zsolt Polgár, professor at the Hungarian University of Agriculture and Life Sciences. After harvesting, the samples were stored in the dark at a temperature of 8 to 10 °C under normal potato storage conditions. Samples of 6 varieties (Arany chipke, Balatoni rózsa, Basa, Démon, Hópehely, Somogyi kifli) and 3 variety candidates (14.21, Balatoni sárga és Golden river) originated. During sample preparation, the potatoes were peeled and chopped into cubes of 1.5x1.5x0.5 cm. I did the cooking at atmospheric pressure. The samples were cooked until they reached a technologically cooked state (35-45 minutes, depending on the variety). After cooking, I cooled it in cold, flow-through tap water until it reached 20°C. The pork samples were made from vacuum-packed pork loin *(longissimus thoracis).* I selected this raw material based on experience results and proper planning. Initially, I made meat samples from pork legs *(biceps femiris),* but rehydration was very difficult and only partially with instrumentally invaluable results. The heterogeneous tissue structure did not allow for uniform rehydration and resulted in sensory-perceptible parts of different textures. The *muscle structure of* the longissimus thoracis is uniform, the direction of muscle fibers is identical, it contains a minimum of tendon or adipose tissue. It also has a nearly constant geometric shape that meets the criteria of economy. Origin of raw material Spain (ES-10.3950/L CE) and Hungary (HU 1360 EC; HU 510 EK). The aim of using meat from different geographical locations and sources was to ensure that my results were generally valid and applicable despite a study containing as many variables as possible. Until the preparation of the samples, the meat was stored between 0-4°C and used in each case on the 8th day since the slaughter of the pig. This method is identical to that recommended by the American Meat Science Association (AMSA). After opening the package, I cut the raw material into 5 cm wide slices in the transverse direction and cooked it in tap water in a kitchen pressure cooker in the ratio of 2 kg meat / 5.0 l water. In both cases, the cooking water did not contain any added salt, spices, or other additives, thus eliminating the change in moisture content and texture due to the osmotic pressure difference. Following cooking, the samples were cooled in the cooking water for 1 hour, then refrigerated at 5°C for 24 hours and stored covered with its own juice all the time, preventing surface drying. Subsequently, meat rectangles and samples measuring 1.27 x 1.27 x 4 cm, parallel to the longitudinal direction of meat fibers, were formed according to the method recommended for measuring the shear force (WBSF) of AMSA (AMSA 2015). The cooking temperature for sample C1 was 100°C for control samples and 120°C for sample C2. During stock analysis of samples C1 and C2, the temperature measured was 80°C, modelling the temperature of freshly served food. The C3 sample was prepared by cooking at 120°C and heated to different temperatures (50°C; 40°C) during the stock tests. Tests and measurements were performed three times in repetition. The rice, pasta, vegetables, fruits, sauces, smoothies, and fish ingredients used in the preparation of the dishes were commercially sourced.

The freeze-drying was performed with a freeze-drying device developed by the Nanofood laboratory of the University of Debrecen. The temperature of the samples was measured with a core thermometer built into the procedure. The freeze-drying process was completed at a core temperature of 42°C, but the minimum drying time was 24 hours in order to complete moisture removal and post-drying operations (Ratti 2013). After the procedure, the samples were immediately packed in vacuum bags at -1 bar pressure using vacuum packaging equipment.

2.2. Methods

2.2.1. Analytical tests

The nutrient and element content measurements were carried out at the Agricultural Instrument Centre of the Faculty of Agricultural and Food Sciences and Environmental Management, University of Debrecen. Sample preparation and analytical tests were carried out in accordance with the relevant regulations of the Hungarian Standards Organization and the Hungarian Food Codex.

2.2.2. Digital image analysis

Microscopic images of meat and cooked potatoes were taken with Olympus MVX10 microscope at 0.63-4X magnification (OLYMPUS Corporation, Japan) with SZX2-ILLK Transmission Light Illumination system (OLYMPUS Corporation, Japan) connected to CellSensEntry 1.18 software (OLYMPUS Corporation, Japan) in the laboratory of the Nutrition Genetics and Genomics Research Group, University of

Debrecen. The digital image analysis was performed with ImageJ 1.54f java 1.8.0_322 (64-bit) software.

2.2.3. Water activity measurement

Water activity was determined according to Walter's description by measuring equilibrium relative humidity (Walter 1931). The relative humidity and ambient temperature were measured with a DHT22 sensor attached to ARDUINO NANO hardware and ARDUINO IDE 2.2.1 software in confined spaces, with a detection time of 1 second until the measurement data remained constant, but at least 24 hours. Based on the measured data, the equilibrium relative humidity values were converted to 25°C using a Mollier h-x diagram for literature comparability. During the calculation, I uniformly considered the atmospheric pressure to be 100 kPa.

2.2.4. Color measurement

Color measurement was performed with a KONICA MINOLTA CR-410 handheld device in the laboratory of the Department of Animal Husbandry, University of Debrecen, by measuring the L* a* b* values accepted by the International Committee for Lighting Technology (Comision Internationale de l' Eclairage - abbreviated as C I E). The ΔELab formula (Mokrzycki and Tatol 2011) was used to determine the color difference. Methods using L* a* b* values are accepted for colorimeter in freeze-dried potato testing (Pieniazek and Messina 2017).

2.2.5. Structural stability method

A structural stability test was performed in the case of potatoes. The freeze-dried potato samples were stored in vacuum packing at room temperature (22°C) away from sunlight in a dark place for 45 days. I fractionated freeze-dried potatoes by size. I separated it into whole fractions (greater than 1cm) and fragmented fractions (between 10-1mm and less than 1mm). The ratio of whole and fragmented parts was expressed as a percentage and correlation analysis was performed with nutrient data from potatoes.

2.2.6. Texture analysis

After two hours of freeze-drying, the sachets containing vacuum-packed meat cubes were opened and rehydrated in a water bath filled with tap water at 30°C, 40°C and 50°C. The time of rehydration used is 2; 4; 6; 8; It was 10 ± 0.5 minutes. The rehydration times were determined in accordance with the requirements of the United States, the

Defense Logistics Agency, the National Combat Logistics Support Agency for food preparation, according to which the preparation time for dehydrated foods for soldiers can be between 5-12 minutes (DLA 2020). The samples were randomly selected during rehydration and the shear force required for pruning was measured directly. The repetition of measurements was 5-8. The prepared samples were performed with a Warner-Bratzler stock tester connected to a TAXT Plus texture analyzer, using a 60° V-groove blade. The speed of travel of the blade was 2.0 mm/s.

2.2.7. Statistical analysis

Statistical analyses were performed using R Studio software (R CORE TEAM 2022). During nutrient analysis, all data were converted to mg/100g units of dry matter. I determined the mean, standard deviation, median, range, minimum, maximum, standard error, and coefficient of variation. The normality of the distribution was determined by Shapiro-Wilk test. If the data showed a normal distribution, then the T-test, if not, the Wilcoxon test (P=0.05) was used to compare the data. In stock studies, the results were converted from g to N multiplied by 0.00980665. Data were evaluated using descriptive statistical methods, a two-sample t-test, and a regression analysis. The relationship between rehydration times at different rehydration water temperatures was determined for each sample by linear modeling according to the following model:

Sensitivity = rehydration water temperature + rehydration temperature

Degradation: origin of sample, date of purchase

$$y = m x + c$$

The principal component analysis was performed with XLSTAT 2024.2.0.1420 - Principal Component Analysis (PCA) with Microsoft Excel 16.017531.

3. Results

The preservation of food is a multidisciplinary discipline in which the variables form a complex system. In order to achieve complexity and results that can be applied internationally, my goal was to explore the widest possible research spectrum. During each study, I selected those food raw materials as samples that I considered relevant for the performance of the measurements and are relevant according to the examination of the hypothesis.

3.1. Nutrition analysis

The nutrient data underlying dietary planning according to dietetic practice are derived from various nutrient tables that contain reference data. Given that military service is a special, demanding task that involves increased physical and mental strain, I believe that dietary planning requires special attention.

The lentil generally known advantages such as production cost, commercial price, shelf life, varied preparation and easy transportability, it also has the advantage that it has the highest protein content of legumes and contains all essential amino acids. Flour made from lentils has a wide range of uses, which has an excellent and balanced nutrient composition.

In terms of protein content, the average amount of the samples was 26.8 g/100g and the median was 27.0 g/100g. The minimum value was 24.4 g/100g and the maximum was 28.6 g/100g. The coefficient of variation was 4.0, which is considered homogeneous. Based on the descriptive statistical analysis of the samples, the homogeneous minerals were Mg, K, Zn, S, P, Cu, S and Ca. Medium variability was shown by the amounts of Fe and Mn. In terms of country of origin, 10 of the 15 samples originated from Canada, so I carried out a descriptive statistical analysis separately for them, based on which the protein content and the amount of Na, K, Ca, Mg, P, Zn, Mn and S of the Canadian samples were homogeneous. There was medium variability in the amount of Fe and Cu. Due to the high degree of homogeneity, the possibility of erroneous inference can be statistically possible, but the chance is minimal, $p=0.05$. I compared my element and nutrient content measurement results with the data published in USDA, England, Australia, FAO 2019, FAO 2012, India, FAO 2017a, FAO 2017b. During the comparison, I found many significant differences. Na, Ca, Mg, Cu showed significant differences compared to USDA, UK, Australia, all FAO, and Indian databases. The quantity of K, Fe, P in part, the amount of Mn showed the least difference compared to the quantities published in databases. The amount of protein content matched the most (50%). The amount of Zn showed no significant difference (p=0.05), except for Australian and FAO data. In terms of database concordance, I found the most differences in the Australian database, which I considered acceptable due to the long geographical distance. For the other databases, there were similarities for 2-4 minerals or proteins tested, but the amount of most minerals showed a statistically significant difference despite the high degree of homogeneity of the samples. Examining the direction of deviations, it can be concluded that the deviation of the measured values was positive, higher than the reference values indicated in the databases. In the case of Ca, Mg, Fe, the difference was almost twofold, which, in my view, is already significant. Due to the above details, I made a separate comparison with the North American databases with the results of the Canadian samples. As a result of the comparative statistical analysis, the protein content of the samples showed no difference compared to the North American databases. The amount of Mn did not differ significantly from the data reported in the USDA database, but the amount of Na, K, Ca, Mg, P, Fe, and Cu differed significantly in each case. Compared to the Canadian database, the amount of each item showed a significant difference, despite the fact that I analyzed samples from Canada. Data were compared with the data published in the New Nutrient Table as the basis of Hungarian dietetic planning (Rodler 2005). As a result of the statistical comparison, significant differences were observed in the amount of Na, K, Ca, Fe and Cu. During my studies, I found significant differences between the mineral content of commercially available lentils and the data of authoritative databases published by the world's largest agricultural and food industry organizations. Of the other reference databases, there were only a few values that could be considered identical (p=0.05) based on the statistical tests used. I found most matches in FAO databases. In various dietary or dietary planning, it is essential to know the exact nutrient composition. Diet planning is based on data from nutrient databases. Most of our mineral content measurement results were homogeneous, which provides a stable basis for further analysis, but the nutrient data showed significant differences compared to the data reported in large databases, even for the same producing country. Based on my results, it can be concluded that it is not possible to develop sufficiently precise dietary recommendations based on the currently available data.

3.2. Image analysis

During the study, I measured the 2D area of the visible surface of the crystallized starch grains on freeze-dried potato samples, made 10 measurements, and calculated a mathematical average from the results. The results of the measurements are shown in table 2.

Table 2: The size of starch in freeze-dried potatoes

Breed/ variety candidates	Area (µm2)
Balatoni sárga	26 635,21
Golden river	20 896,01
Hópehely	17 032,35
Basa	11 938,24
Arany chipke	9 407,26
14 21	8 174,22
Balaton rózsa	5 194,15
Démon	2 729,72
Somogyi kifli	1 737,04

The starch particle size of freeze-dried potato samples was compared with the nutritional content of the potatoes by correlation analysis. Evaluating the literature data and my measurements, the difference in starch granule size between cooked and freeze-dried condition was caused by the different amounts of amylose and amylopectin. Somogyi kifli, with the smallest starch granule size, is likely to be a high amylose variety based on literature descriptions, while Balatoni sárga is a high amylopectin variety. The potatoes I had studied were freeze-dried in the cooked state and therefore the swelling capacity of the starch granules has a great influence on the size after freeze-drying. The r value between the size of the starch grain and the protein content of freeze-dried potatoes is -0.573 and its starch content is -0.628, which is statistically a medium correlation, indicating a significant relationship. The r value among the dry matter content of raw potatoes is -0.895, which indicates a high correlation, indicating a marked relationship between the variables.

The correlations are shown in Figure 1.

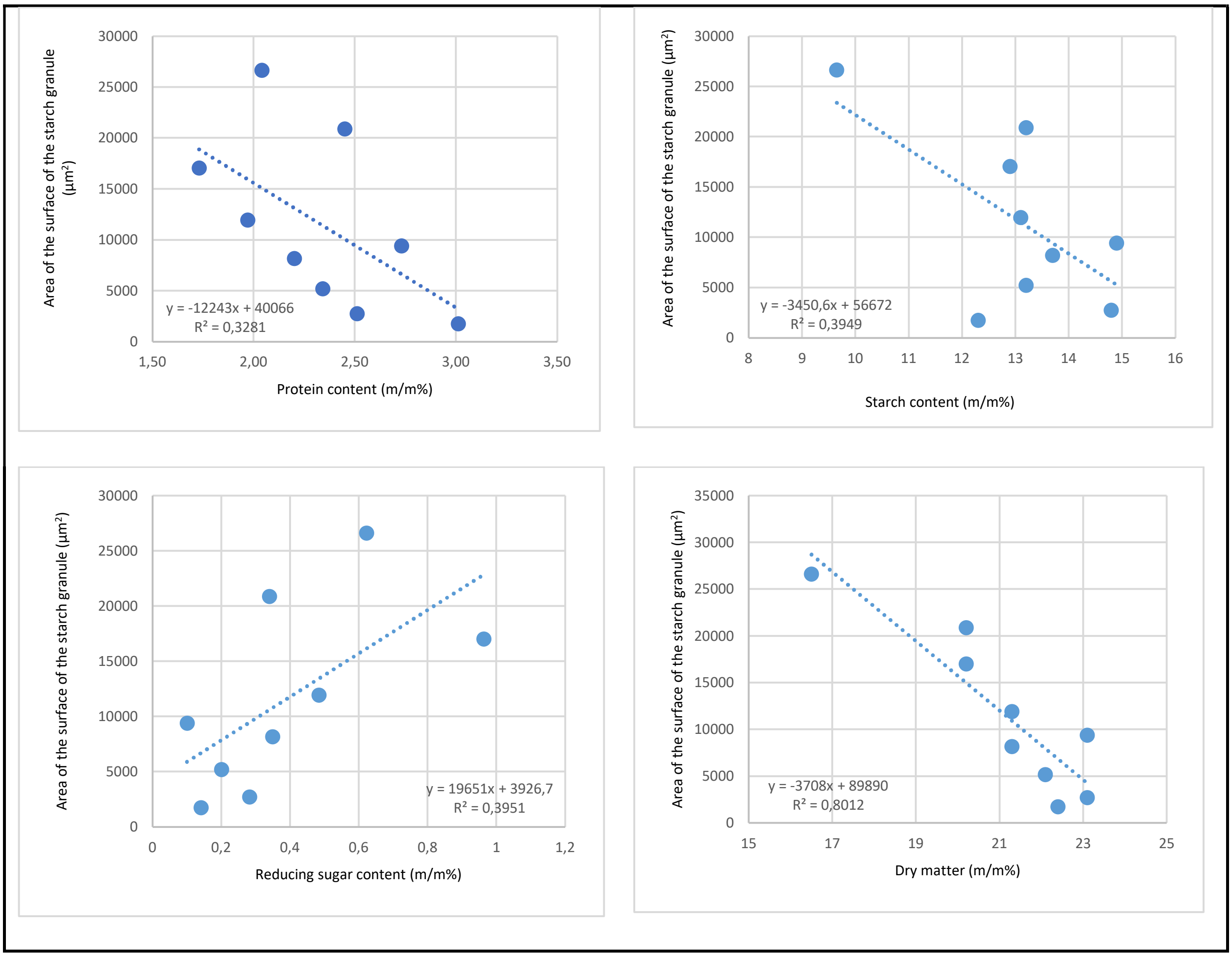

Figure 1: The relationship between starch grain and nutrient content in freeze-dried boiled potatoes

3.3. Water activity and oxidation

Data and results related to water activity measurements are presented in table 3:

Table 3: Equilibrium relative humidity over freeze-dried foodstuffs indoors and water activity calculated from data

Material	Measuring temperature (°C)	ERH%	ERH% 25°C	aw
Pork loin	22,1	12,0	~10	0,1
Pork stew	22,2	12,1	~10	0,1
Boiled potatoes (Somogyi kifli)	22,1	12,1	~10	0,1
Boiled potatoes (Balatoni rózsa)	22,1	12,1	~10	0,1
Boiled rice	22,0	12,0	~10	0,1
Spaghetti sauce	22,1	12,1	~10	0,1
Pasta	22,2	12,0	~10	0,1

The results I measured are similar to the water activity values published by other authors, so I accepted them. Water activity affects not only microbiological activity but also biochemical deterioration processes. In terms of fats, a water activity value of 0.3-0.5 is desirable (Troller 1989). High water activity has an inhibitory effect on the initial oxidation of the lipid, but secondary reactions of lipid degradation products enhance the oxidation of proteins (Kanner and Karel 1976). Oxidation affects not only lipids but also proteins (Di Bernardini, et al., 2011). Free radicals formed in proteins react with peroxide lipids. The results of the measurements related to the rancidity of the foods I prepared are shown in table 4:

Table 4: Results of rancidity test in freeze-dried foods (date of analysis: month of June 2023, date in sample name indicates date of preparation)

	Loin 2022.04.	**Loin 2023.02.**	**Herring 2023.02.**	**Lecsó 2022.04.**	**Spaghetti sauce 2023.02.**	
Acid number (mg KOH/g fat)	8,48	5,29	9,34	14,10	7,22	Result obtained on freeze-dried sample
Peroxide number (meq. O_2/kg fat)	58,80	37,20	135,00	544,00	28,60	
Acid number (mg KOH/g fat)	2,88	1,80	2,80	3,67	0,79	Result calculated for rehydrated mass
Peroxide number (meq. O_2/kg fat)	19,99	12,65	40,50	141,44	3,15	

When evaluating the data, the Hungarian Codex Alimentarius generally uses the term "free of foreign odor" for foodstuffs to establish the fact of rancidity, with the exception of Directive 2-221 on edible oils, it does not set specific limit values. Virgin and cold-pressed edible oil shall have an acid number not exceeding 4,0, palm oil shall not exceed 10,0 mg/KOH/g and a peroxide number not exceeding 10,0 meq. O_2/kg fat may be. In the case of animal feed, the Minister for Agriculture and Rural Development 45/2001 of 25 December 2001 According to Annex 6 of FVM Regulation, the maximum acid number of the feed is 50 mg/KOH/g, and the peroxide number is maximum 25 meq. O_2/kg fat (Hungarian Gazette 2001/7). I compared my results with those reported by other authors. Freeze-dried ground beef has a peroxide number of 10.42 meq. O_2/kg (Aksoy et al. 2019), freeze-dried pork at 6 weeks atmospheric pressure in an environment containing silica gel 83.3 meq. O_2/kg (Rahman et al. 2005). Based on the comparison and the requirements of the Hungarian Food Codex, I rate the values I measured as generally high. The fact that non-commercially purchased ready-made foods did not contain antioxidant additives contributed to rancidity, and in the case of commercially purchased ones, the amount of additives during production was not tailored to the applied technology. The packaging technology and packaging material used were not specific.

Based on the above, the greatest danger is the oxygen remaining in the system, so it is recommended to use N_2 or Ar protective gas or vacuum suitable for food industry for storage in light- and oxygen-impermeable packaging.

3.4. Color measurement

Correlation analysis was performed by comparing the values determining the colour of potatoes and their nutrient content. The correlation between the amount of reducing sugars in the dry matter and the colour measurements was -0.4279 for L* and -0.4471 for b* for cooked potatoes, the relationship was low, after rehydration the correlation with a* was 0.4947. When analyzing the differences in colour values, the magnitude (ΔL*) and correlation of the change in brightness between raw and cooked potatoes was 0.5789. An increase in the level of reducing sugar in raw potatoes led to an increase in the brightness of the cooked product, this change was observed in both boiled and rehydrated potatoes. The correlation coefficient was 0.5096, indicating a moderate positive correlation between the amount of reducing sugars and the change in Δa*. In addition, the magnitude of the change Δa* also showed a positive correlation with 0.5288. There was a strong negative correlation between starch in dry matter and a* in raw potatoes (-0.7196), suggesting a significant relationship. In addition, the amount of starch in freeze-dried potatoes L* showed a correlation coefficient of 0.5770, which was maintained and measurable even after rehydration (0.6079). The relationship between raw and cooked potatoes was strongest for colour parameters Δa* and Δb*, with correlation coefficients of -0.7464 and 0.6076, respectively. There was a moderate correlation between the lightness parameter ΔL* of cooked and rehydrated potatoes, with a correlation coefficient of 0.5796. The amount of protein in the dry matter showed a moderate negative correlation with the L* lightness parameter of raw potatoes (r=-0.6055, b*=0.6116). However, this correlation decreased after rehydration, with a decrease in L* to a correlation coefficient of 0.4514 and a correlation coefficient of -0.5337. I measured a significant relationship between the protein content and colour (b*) of potatoes calculated on dry matter, as evidenced by the correlation coefficient of 0.6878 in boiled potatoes. The correlation between protein content and changes in L* value between raw and cooked stock was -0.7168 and -0.5268 between cooked and rehydrated L*. Correlation analysis was also performed between the examined results of structural stability and the results of light metering. The correlation between whole unfragmented freeze-dried boiled potatoes and raw L* is -0.6112 and between cooked value is 0.5812. The change in brightness between raw and cooked potatoes and the relationship between the parts remaining whole was 0.7013.

3.5. Texture analysis

The herd change measurements were made on rehydrated pork loins. The magnitude of the coefficient of variation of the measurement results was relatively high, which statistically indicates medium to strong variability. Before accepting or rejecting the data, I had made a comparison with the coefficient of variation values of the results of WBSF measurements measured by other authors, the data showed similarities, so I accepted them. The results of rehydration measurements at 50°C and the regression line between rehydration time and shear force are shown in figure 2.

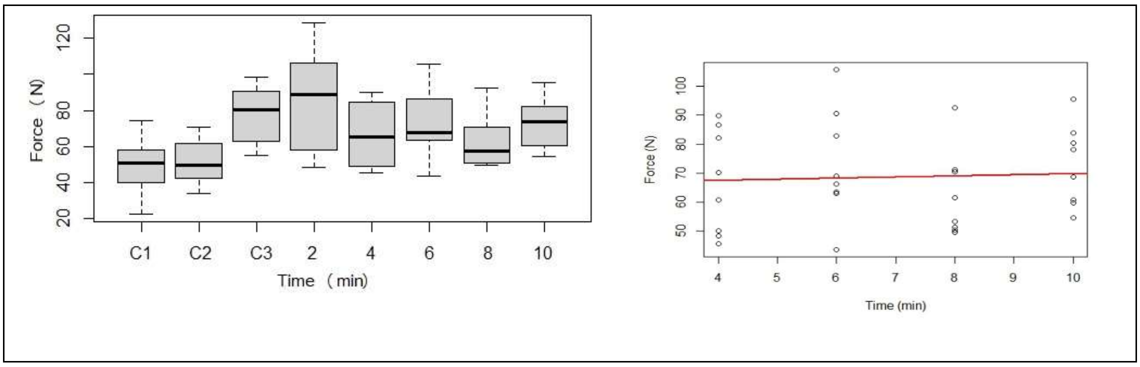

Figure 2: Average maximum shear force value of freeze-dried pork loin rehydrated at 50°C according to rehydration times (C1 = control 100°C; C2 = control 120°C; C3 = control 50°C) and maximum shear force value and regression line according to rehydration times

In the stock test at 50°C, the averaged maximum shear force results were higher than those of the C1 and C2 control samples heated to 80°C, but this difference was no longer observed for control samples reheated to 50°C. The difference is due to the different temperature (Laakkonen 1973), so I accepted it. During data evaluation, the coefficient of variation of the measurement results for 2-minute data was 34.6, indicating strong variability, but this value decreased steadily with increasing rehydration time to 19.4 by 10 minutes. For the regression values, R2 was 0.0385 (p-value: 0.804), which did not allow a linear relationship between the variables to be demonstrated.

The results of rehydration measurements at 40°C are shown in Figure 3.

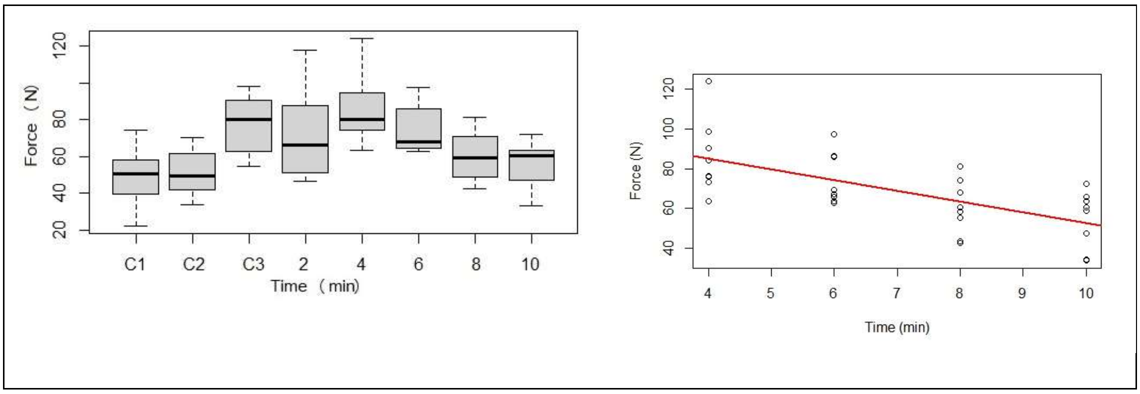

Figure 3: Average maximum shear force of freeze-dried pork loin rehydrated at 40 °C according to rehydration times (C1=control 100°C; C2=control 120°C; C3=control 50°C) and maximum shear force value and regression line according to rehydration times

Due to the high value of the coefficients of variation (CV=17.6-24.7), further statistical calculations were performed to examine the possible relationship between rehydration time and maximum shear force. During the data analysis, only the results of measurements made at 40°C were taken into account. In order to determine the difference between actual and statistical terms, a two-sample t-test was performed, the results of which are shown in Table 5.

Table 5: Results of T-tests between rehydration periods (p-value)

Rehydration time (min.)	4	6	8	10
4	-	0,062	0,079	0,006*
6		-	0,735	0,209
8			-	0,509

* Significant difference ($p \leq 0{,}05$)

Based on the results of the two-sample t-test ($p \leq 0.05$), it can be concluded that there is no significant difference between the 4-6-, 6-8- and 8–10-minute results, but there is a significant difference between the 4- and 10-minute results despite the large variation. To determine the relationship between rehydration time and the required shear force, a regression analysis was performed. During the analysis, averages of the maximum force required for shear according to units of time (4, 6, 8 and 10 minutes) were calculated. The best results were achieved during rehydration at this temperature. The magnitude of the force required for shearing was lower than that measured at 40°C and after 10 minutes of rehydration I reached the force required for shearing of control samples heated to 80°C. A gradual downward trend can be observed from the measurement result starting at 4 minutes. To establish the relationship, the regression analysis was performed with the results obtained at 4, 6, 8 and 10 minutes. The result of the analysis was R^2=0.976 and corrected R^2=0.964 (p-value = 0.0121), suggesting a strong dependent relationship between stock hardness and time change during rehydration at 40°C.

The equation for the straight line is y= -5.406x+106.65

Based on multiple confirmatory calculations, it can be determined that there is a linear, strong dependent relationship between variables. During the rehydration tests at 40°C I managed to achieve the structural material measured in the C1, C2 and C3 control samples.

The results of rehydration measurements at 30°C and the regression line between rehydration time and shear force are shown in Figure 4.

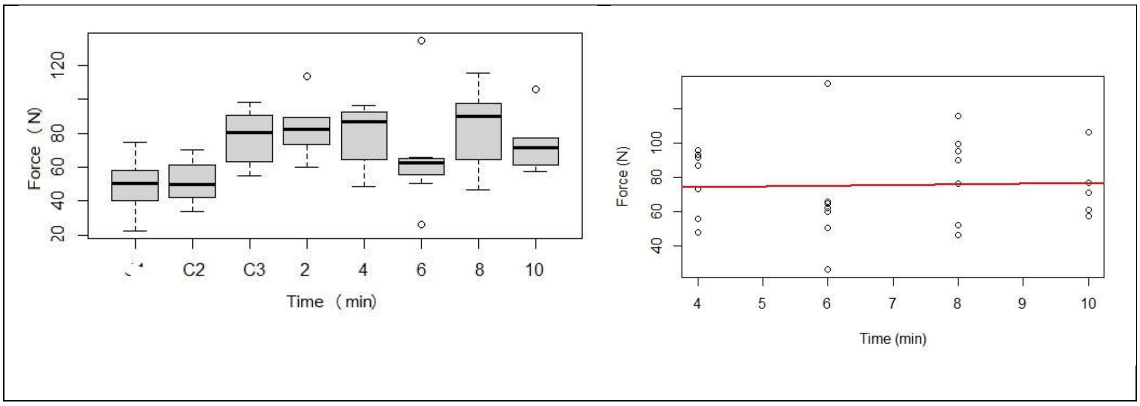

Figure 4: Freeze-dried pork loin rehydrated at 30°C mean maximum shear force value according to rehydration times (C1=control 100°C; C2 = control 120°C; C3= control 50°C) and maximum shear force value and regression line according to rehydration times

In tests at 30 °C rehydration it was not possible to obtain values measured at 80°C for control samples. The largest deviations and the largest outliers were measured during tests at this temperature. The result obtained during the regression analysis was R^2=0.0141 (p=0.882), the lowest result I experienced during my measurements. Based on the data, it was not possible to show a linear relationship between the variables on this rehydration Average Shear Force (WBSF) results are summarized in figure 5.

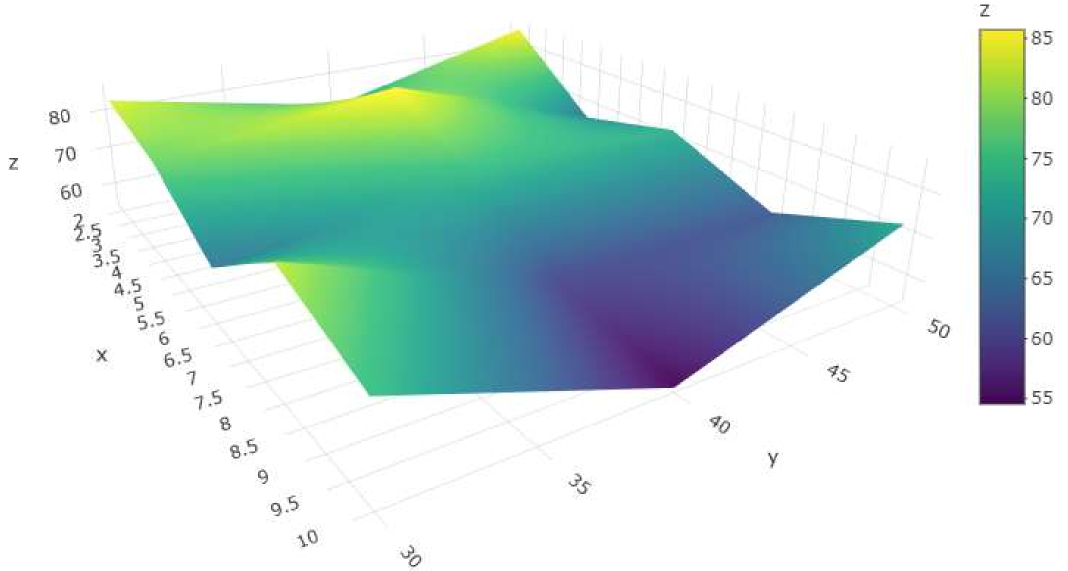

Figure 5: Surface diagram of the relationship between the force required to mow and rehydration at different temperatures and times, where x=time (min), y=rehydration water temperature (°C), z=WBSF (N)

3.6. Structural stability test

A correlation analysis between the fractionation results and the nutrient content of potatoes was performed to determine the nutrient content that is associated with the change in structural stability of freeze-dried cooked products. The results of the statistical analysis by nutrient content are shown in figure 6. The analysis was performed using the whole parts ratio.

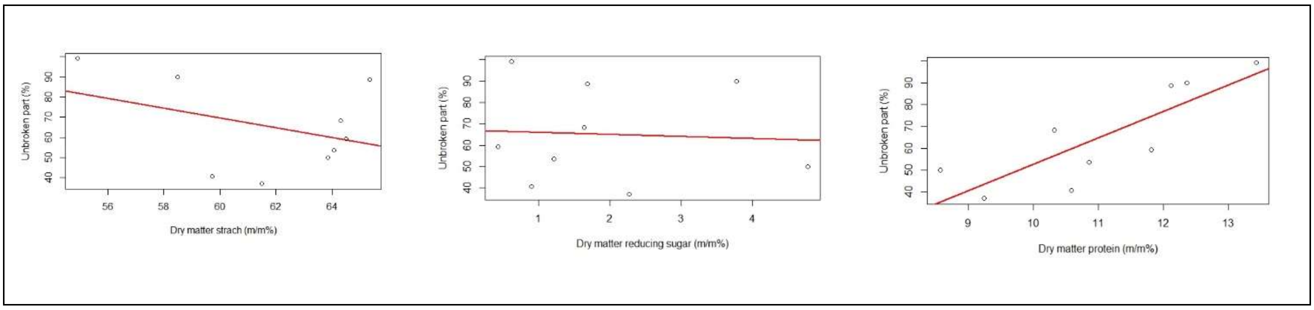

Figure 6. Freeze-dried potato structural stability and correlation results for potato dry matter

The correlation between the calculated starch content and stability structural test was -0.3723, R^2 was 0.0140 (p=0.05), statistically there is no relationship between the variables. The correlation between the reducing sugar content calculated on dry matter and the stability structure test was -0.0602, R^2 was 0.0036 (p=0.05), statistically there is no relationship between the variables. The correlation between the protein content calculated as dry matter and the stability structure test was 0.8276 and R^2 was 0.685 (p=0.05), which indicates a statistically strong relationship between the variables.

The equation for the straight line (average) is $y= 12.065x+68.029$

Research results or studies on the characteristics of freeze-dried boiled potatoes are limited. The result of the correlation analysis shows that the presence of protein contributes significantly to the structural stability of cooked potatoes in the freeze-dried state, while starch and reducing sugars have no relevant relationship in this regard. When comparing the results of the structural stability study, microscopic images show that varieties with weaker performance, such as "Balatoni rózsa", "Basa" and "Hópehely", have a fragmented, deeply open, large-grained, floury structure. In contrast, well-performing varieties such as "Balatoni sárga" and "Somogyi kifli" have a coherent, crack-free, waxy structure. My observations and results are consistent with those reported by Martens and Thybo (Martens and Thybo 2000).

Combining the results of potato nutrient content, colorimetry and structural stability tests, principal component analysis was carried out to identify variables that can be used to select varieties suitable for preservation by freeze-drying technology in the cooked state. The variables selected are nutrient content, clarity and colour values in the raw and cooked state. These variables will be the components that can be easily measured before the application of the process, thus facilitating the selection of suitable varieties. The results are as follows.

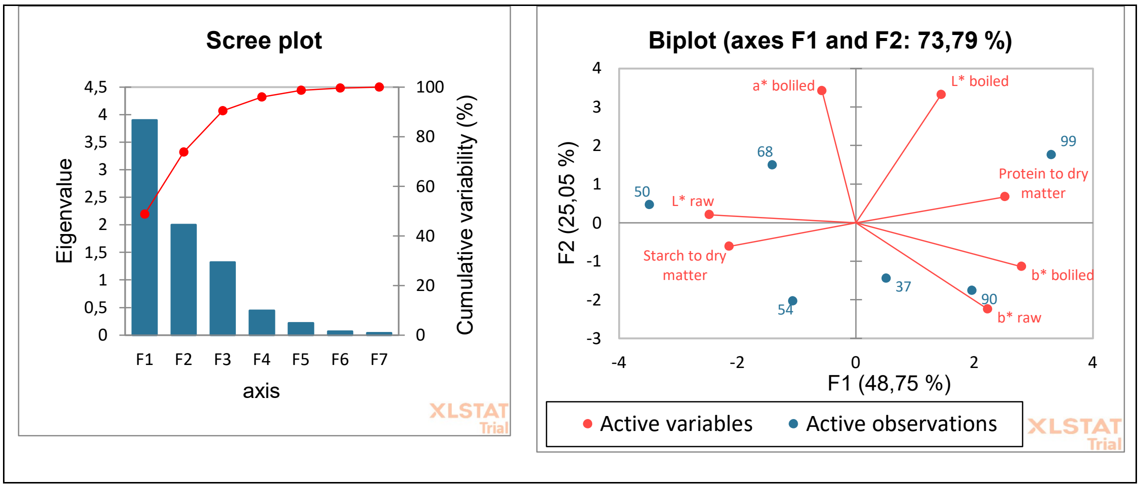

Figure 7: Results of analysis of the main component of freeze-dried boiled potatoes

Based on the results of the main component analysis, it can be concluded that, in addition to the high protein content in dry matter, the results of the potato colour measurement in raw and cooked state can be used to determine the characteristics of the appropriate potato variety. According to my results, the potato variety with good structural stability has a high protein content, lower L* and higher b* values.

Evaluating the results, it can be concluded that there is a relationship between the nutritional content and physical characteristics of foods, which has an impact on the quality of freeze-dried food.

3.7. Rehydration test

Determining the amount of water needed for rehydration is essential for proper rehydration to take place. In the introductory part, I mentioned the importance of proper rehydration and the problems the U.S. military encountered related to inadequate rehydration. In my opinion, this is the most critical and important phase from the point of view of the practical applicability of technology (e.g. military food packages), which, based on my studies, is complex and influenced by several factors. In order to determine the amount of water required for rehydration, it is necessary to determine how much water the product lost during freeze-drying. Based on the moisture removed, I determined the amount of water needed for rehydration. From the point of view of practical use, I calculated meats with 70% pasta, 80% potatoes, 80% sauces, 80% smoothies, 90% moisture content, and based on this I determined the amount of water needed for rehydration.

During rehydration, large cracks can be seen on the structure of the Balatoni rózsa, the Demon and the Basa and the structure completely disintegrated, while the Arany chipke, Balatoni sárga and Somogy kifli retained their original character. The cracks visible on the surface of the Somogyi kifli stopped about 1 mm deep from the surface and its structure remained stable.

Organoleptic analysis was performed on potato samples rehydrated at different temperatures involving five soldiers. During the study, only the sensation in the mouth had to be taken into account, how similar the texture of the product was to the consistency of the original cooked potatoes. For the evaluation, I used a score system from 0 to 10, 0 indicates the least, 10 indicates the best. Taste occurred during rehydration in 2, 4, 6, 8 and 10 minutes. As a result of the consistency test, it can be concluded that the Somogyi kifli and Balatoni sárga varieties' performance was the most stable and best under the examined conditions. In nutrient tests, these varieties had the highest amount of protein calculated on dry matter (Balatoni sárga 12,36 m/m%, Somogyi kifli 13,44 m/m%).

Comparing the experience of the rehydration studies of boiled potatoes with the results of Table 2, it is an interesting fact that varieties with the smallest and largest starch grain sizes proved to be beneficial. Based on the results, it can be concluded that, in the case of boiled potatoes, the size of starch grains in freeze-dried state has no effect on rehydration, structural stability or quality characteristics.

Based on the foregoing, a special balance should be established through the capillaries so that the rehydration fluid flows towards the inside of the product at the appropriate speed, however, the capillaries are not blocked due to the saturation of the outer layers. Taking this into account, it can be estimated that raising the temperature of the water bath above the glass transition temperature of lyophilized solids may cause a sudden structural collapse resulting in a decrease in the porosity of the product. This not only results in lower water absorption at higher temperatures, but also reduces the rehydration rate and can shift mass transfer control from capillary to diffusion. Increasing the temperature at different levels above the glass transition temperature can cause further collapse of varying degrees. Based on the results of tests at 40°C, this temperature is below the glass transition of pork loin, which is sufficient for uniform rehydration and sufficient moisturizing liquid enthalpy for rehydration to take place.

3.8. Military field test

In May 2022, at the training ground of the Hungarian Defence Forces in Táborfalva, I carried out sensory and applicability tests involving 30 soldiers from the staff of the Institute of Modernization under camp conditions. The food tested was pork loin with lecsó (hungarian ratatouille) and mashed potatoes. The soldiers were given a questionnaire; a form on which food had to be scored based on a point system ranging from 0 to 10. The results are as follows:

- Food colour: 8.9
- Food texture: 8.6
- Overall impression of food: 7.4
- Suitability for military food: 8.3
- Rehydration time length: 8.8
- Temperature required for rehydration: 8.9
- 'Would you like to consume it?': 7.2
- How similar it is to a freshly prepared dish: 7.6
- **Average score: 8.2**

The team test has complex results, because the opinion of the soldier who uses and consumes the product is crucial. The average score of 8.2 points obtained during the evaluation is a result in the upper quartile, which is certainly a positive assessment confirming the legitimacy of freeze-dried foods among foods supplied during military supply. The results of the study provide a stable basis for further development and research.

2. Analysis of hypotheses

Accepting the hypotheses formulated to achieve the objectives set at the beginning of my research and to answer the questions posed requires complexity and complexity of verification due to the multiple methods and tests used, and therefore the acceptance or refutation of hypotheses according to hypotheses will be presented in this chapter.

H1: ***The data reported in the international and national nutrient databases do not differ significantly from the nutrient and element content of commercially available raw materials.***

In the analysis of hypothesis 1, I wanted to investigate whether it would be feasible to develop a diet specifically designed for military personnel containing macro- and micronutrients based on the available nutrient data. In most cases, the nutrient and elemental content of the medium grain brown lentils I examined differed significantly from the data reported by leading world organizations and domestic nutrient tables. Based on my measurements, **I did not accept hypothesis 1, which concludes that the data reported in international and domestic nutrient databases are significantly different from the nutrient and element content of the commercially available raw material.**

H2: ***Freeze-drying technology can be used to ensure the microbiological, chemical, and physical stability of the finished product.***

In the analysis of hypothesis 2, I considered food as a complex system where stability is most affected by water activity according to the literature. With sufficient water activity, microbiological and enzymatic stability can be achieved, but at the same time, the degradation of fats becomes intense, so I supplemented my studies with acid number and peroxide number measurements. The results show that a sufficiently low water activity and microbiological stability can be achieved, but at the same time, the degradation of fats and proteins becomes intense, which makes the use of antioxidants and appropriate packaging techniques essential. It is important to note that low water activity does not in itself sterilize but inhibits the activity of microbes, so the microbiological status of the food, whether it is established during heat treatment or in the original food, is a key issue for the subsequent consumption. **I adopted my hypothesis with the consideration and addition of autooxidation, i.e., the microbiological, chemical, and physical stability of the finished product can be achieved by freeze-drying technology with the use of antioxidants and appropriate packaging technology.**

H3: ***The nutritional content and physical characteristics of foods have no effect on the quality of freeze-dried food.***

In the analysis of Hypothesis 3, I examined whether there is a correlation or relationship between the available data and the specific characteristics of the product that will be suitable to meet military logistics needs. In my tests, I observed that the greatest change during storage occurs in cooked freeze-dried potatoes hence I chose to accept or reject this hypothesis. During my tests I was able to identify several correlations, and I also used principal component analysis to examine the data. **On the basis of my results, I did not accept my hypothesis that the nutritional content and physical characteristics of food have an effect on the quality of freeze-dried food.**

H4: ***By using the right raw materials and preparation methods, the original texture and character of the food can be achieved during rehydration at low temperatures below 50°C and in less than 10 minutes.***

The analysis related to the acceptance or rejection of hypothesis 4 is the most relevant to the quality of the final product in my research. The basis for determining the time required for rehydration is based on the United States military's requirement, which is a guideline for NATO compatibility. Enjoyment value is also a very important attribute, but the most important is the military team test. Based on the results of the WBSF measurements, it has been possible to achieve, with appropriate preparation during low temperature rehydration, a stock of the original food and to identify potato varieties that have shown favorable characteristics in sensory tests. I consider the results above the upper quartile obtained in the team trial as positive. **On the basis of my results, I accepted my hypothesis that with the right raw materials and preparation methods, the original composition and character of the food can be achieved by rehydration at low temperatures below 50°C and in less than 10 minutes.**

3. New scientific results of the thesis

1. Nowadays, cultivated and commercial lentil nutrient and element content varied significantly in a positive direction in terms of the magnitude and size of the difference, with almost double the amount of Ca, Mg and Fe compared to the nutrient and element content of the lentils used as the basis for the data series and as reported in the nutrient databases in use and in the guidelines.

2. There is a strong dependent relationship (R2=0.976) between the time required for rehydration and the maximum force required for shearing during rehydration of freeze-dried cooked pork chops at 40°C.

3. There is a statistically significant [r= ± (0.9-1.0)] and strong [r= ± (0.7-0.9)] relationship between the parameters determining the colour of potatoes in different technological states and their variation in magnitude and the protein, starch and reducing sugar content on dry matter. There is a significant (r = -0.895) relationship between the size of the 2D visible area of the starch granules of potatoes in the freeze-dried state and the dry matter content of potatoes in the raw state.

4. There is a statistically significant relationship (r=-0.8276) between the protein content per dry matter of potatoes and the structural stability of freeze-dried boiled potatoes.

5. Among the methodological results, the meat size recommended by AMSA for WBSF measurements can be successfully applied to the production of freeze-dried meat products, and the structural stability test method I developed can be successfully applied to the testing of freeze-dried boiled potatoes.

6. Based on the results of the team test, the ingredients, raw materials, and characteristics of the freeze-dried ready meals should be sized and designed primarily for proper rehydration.

4. Practical applicability of the results

1. Freeze-dried ready meals meet the requirements for military use. The use of properly selected ingredients and preparation methods for the foods under study, as I had suggested, will avoid the rehydration problems experienced by the US military for the foods under study. Given the higher cost of production per unit, the technology can be applied to supply the harder to reach special military operations.
2. During the team trial, the participating staff positively evaluated the freeze-dried product. Summarizing the results of the team trial, the food produced using freeze-drying technology is suitable for military supply.
3. With the proper selection of ingredients and preparation method, the bite size of the freeze-dried food will be appropriate to the nature of the food, which will greatly contribute to increasing of the enjoyment value of the food through the sense of chewing, thus enhancing the quality of the freeze-dried food.
4. Due to the differences in the measured nutrient and element content of raw materials and the nutrient and element content of databases, it is recommended to implement food raw material procurement procedures in a targeted manner, supplementing the requirements with nutrient quantity requirements. For planning purposes, it is recommended to carry out own analytical measurements, e.g. when planning the supply of special ranks, rotary and fixed wing pilots or special military operations.
5. Using the ingredients and preparation methods I propose, the rehydration of the finished dish using 40°C rehydrating water is achieved within 10 minutes to the extent that it is suitable for consumption, saving time and energy.
6. The results of the potato trials will provide useful information for plant breeders, which will enable target agricultural production for the identification and breeding of potato varieties suitable for freeze-drying. Of the varieties tested, Somogyi kifli was found to be the most suitable for freeze-drying in the cooked state.

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List of publications related to the dissertation

Hungarian scientific articles in Hungarian journals (2)

1. **Répás, Z.**, Bakos, C. A., Hajdú, F., Buzás, B. O., Győri, Z.: A Magyar Honvédség élelmezésellátásának modernizációs lehetőségei.
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