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CHAPTER 5

Technology of multilayer and glazed fruit and vegetable chips

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Abstract

Fruit and vegetable chips are a growing segment of the global snack market. These chips are an alternative to high-calorie potato chips. Fruit and vegetable chips can be a useful snack between main meals, allowing the human body to get the necessary vitamins, macro and micro elements. No oil is used in the production of fruit and vegetable chips, and they do not contain added sugar, artificial colours and flavors. Instead, these chips contain beneficial substances that are rich in fresh fruits and vegetables, albeit in smaller quantities.

Because fruits and vegetables lose valuable nutrients during storage, they must be processed into high-quality fruit and vegetable chips. Blanching, immersion in various solutions and osmotic dehydration of the plant raw materials before drying are used to reduce the loss of nutrients during the production of fruit and vegetable chips and to preserve the taste, smell and colour of the plant raw materials in the finished product. The developed technologies of multilayer and glazed fruit and vegetable chips allow consumers to obtain an innovative product with original taste properties and nutritional composition. The modes of the proposed technology of multilayer chips allow producers to preserve as much as possible the taste and colour of plant raw materials (fruits and vegetables) in the finished product, as well as nutrients. As a result of combining different types of plant raw materials (vegetables, fruits, seeds) it is possible to obtain a wide range of multilayer chips with different tastes that can satisfy the preferences of different categories of consumers. By combining plant raw materials, manufacturers can also balance the nutrient content of the chips and obtain a functional product for specific target groups of consumers.

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The proposed chocolate-glazed (with black, white or milk chocolate) multilayer chips are a promising product in the sweet chips segment. The use of chocolate makes it possible to balance the nutritional value of the multilayer chips, and the addition of freeze-dried plant powders (fruits, vegetables, berries) or their combination to the glaze enriches the product with vitamins, macro and micro elements, and gives the chips new flavors and colours.

Keywords

Fruit chips, vegetable chips, multilayer chips, glazed chips, technology of fruit chips, technology of vegetable chips, healthy chips, properties of chips.

5.1 Introduction

Snacking is the modern trend in eating patterns, defined as eating outside of the main meals (breakfast, lunch and dinner). The popularity of snacks is due to urbanization, accelerated pace of life, economic and social factors, etc. If the energy intake from a meal is less than 15 % of the recommended daily energy intake, it is a snack [1]. In the global market, a significant segment of snacks consists of salty and sweet foods that can contribute "empty" and excess calories that do not provide essential nutrients to help consumers meet their nutritional needs [2]. In addition, snacks are often considered a major contributor of fat and simple carbohydrates to the diet [3]. This has led most consumers to believe that snacks are unhealthy foods. Also, snack food consumption is often associated with the socioeconomic status of consumers. Low socioeconomic status is thought to lead to the consumption of foods that are low in nutrients but high in energy [4]. But proper snacking has a number of health benefits related to appetite control and weight management [5]. Eating nutritionally balanced snacks with vitamins and minerals between main meals may contribute to meet the recommended daily intake of healthy foods [1]. To achieve a positive effect from snacking, it is important to plan snacks properly and consider their energy value, taking into account a person's age and lifestyle.

The most popular snack in the world is potato chips, which are prepared by deep-frying raw solid potato slices or pre-cooked and dried potatoes in the form of flakes or powder with starch in vegetable oils [6]. Dried onion, garlic, parsley, celery and dill, mushrooms, cabbage, carrot, salt, etc. are added to the potato chips to enhance the taste and flavor. Spicy and aromatic parts of plants (seeds, roots, bark, leaves, flowers, etc.) are also used to improve the sensory properties of potato chips.

During deep-frying, the physical, chemical and sensorial characteristics of potato chips are modified [7]. In fried foods, the amount of fat reaches 1/3 of the total weight of the food, which can pose a risk to human health [8]. Methods to reduce oil absorption by fried foods have been developed [7, 9]: soaking potato slices in NaCl solution; frying potato slices in vacuum; blanching potato slices before frying; microwave treatment of potato slices; drying or baking potato slices before frying; using hydrocolloids added to the breading coating to create a barrier against oil absorption.

When potato chips are fried at high temperatures (170–190 °C), acrylamide, a potentially carcinogenic compound, is also formed [10]. Acrylamide content in potato chips can range from 211 to 3515 μg kg^{-1} [11]. During frying in oil, vitamin C losses in potatoes can reach 83.35 %, depending on the heating level and time [12]. Changes in the mineral content of fried potatoes are caused by water loss. Due to the high starch content of potatoes, potato products are among the products with a high Glycemic Index (GI), in particular, the Glycemic Index of potato chips is 77 ± 4 [13].

The driving force in the snack market is the development of allergen-free, vegan and gluten-free natural products with reduced calories, sodium and saturated and trans fats [14]. Consumers also choose snacks based on price, brand, taste and packaging that extends shelf life without compromising quality. Fruit and vegetable snacks are growing in popularity due to changing lifestyles and a focus on healthy eating, especially products fortified with vitamins, minerals, antioxidants and plant extracts that are low in fat, salt and sugar and free of synthetic food dyes, additives and GMOs. Chips made from vegetables, fruits, berries, and grains are one of the most common types of plant-based snacks. Drying, frying, baking, extruding, or a combination of these techniques are used to produce plant-based chips.

The development of new vegetable and fruit chips, with the possibility of combining different plant-based ingredients in one product, is promising for the expansion of the snack range.

5.2 Nutritional value of plant-based ingredients for chips

Vegetables, fruits, berries, seeds and their processed products are plant-based ingredients for chips. Various types of chocolate, a product made from roasted and ground cocoa beans, are used to glaze the chips. Fruits, vegetables and other plant-based ingredients in chips have high nutritive value in both raw and processed forms. This section provides a brief description of the nutritional value of certain types of plant raw materials used in the production of fruit and vegetable chips and chocolate-glazed chips.

5.2.1 Apple

Apple fruits are a source of organic acids, vitamins and minerals (mg 100 g^{-1}) [15, 16]: malic acid – 919±109; citric acid – 21.5±3.7; ascorbic acid – 24.14±0.18; sodium (Na) – 3.76–23.70; potassium (K) – 112.3–795.1; calcium (Ca) – 4.43–26.39; magnesium (Mg) – 7.99–21.82; iron (Fe) – 0.28±0.02; zinc (Zn) – 0.19±0.02; manganese (Mn) – 0.04±0.0; copper (Cu) – 0.05±0.0. Apple fruits have a high sugar content of 8.9–15.0 % and water content of 76.7–88.4 %, and also contain soluble dry matter of 10.8–16.5 % and ash in the amount of 1.6–2.8 % [15]. The polyphenol content of apple fruit is in the range of (mg 100 g^{-1} DW) [17]: flesh – 9.6–41.6; peel – 36.39–256.19. For the production of chips, it is recommended to use sour and sweet-sour varieties of apples with soluble sugar content of 13.0–14.7 %. The nutritional value of apple is as follows (g 100 g^{-1}) [18]: protein – 0.3; fat – traces; carbohydrates – 12.0; fructose – 5.6; glucose – 1.8; sucrose – 2.6.

5.2.2 Pear

Pears are a nutrient-rich fruit, containing the following nutrients (%) [19]: water – 84.9; protein – 0.3; fat – 0.1; carbohydrates – 14.4; dietary fiber – 1.9. The mineral content of pears is in the range of (mg kg^{-1}) [20]: sodium (Na) – 3.2–138.6; potassium (K) – 2685.1–9212.7; calcium (Ca) – 303.1–2424.9; magnesium (Mg) – 16.0–765.3; iron (Fe) – 6.0–52.0; zinc (Zn) – 2.8–16.9; manganese (Mn) – 1.2–6.8; copper (Cu) – 1.5–11.6; phosphorus (P) – 353.3–1799.8. The content of vitamin C in pears is in the range of (mg 100 g^{-1}) [21]: flesh – 9.1–29.7; peel – 9.5–35.9. Other vitamins are contained in this amount (mg 100 g^{-1}) [18]: vitamin E (α-tocopherol) – 0.12; thiamin – 0.012; riboflavin – 0.025; niacin – 0.157; pyridoxine – 0.028. The pear peel has a higher phenolic content than the pear flesh [21]. The sugar content of pears is as follows (g 100 g^{-1}) [18]: fructose – 5.3; glucose – 4.2; sucrose – 1.2; total – 10.7.

5.2.3 Carrot

Carrot is a source of carbohydrates and minerals; it contains the following nutrients (%) [22]: water – 86–89; protein – 0.7–0.9; fat – 0.2–0.5; carbohydrates – 6.0–10.6; dietary fiber – 1.2–2.4; ash – 1.1. The mineral and vitamin content of carrots is as follows (mg 100 g^{-1}) [22]: sodium (Na) – 40.0; potassium (K) – 240.0; calcium (Ca) – 34.0; magnesium (Mg) – 9.0; iron (Fe) – 0.1; zinc (Zn) – 0.2;

copper (Cu) – 0.02; phosphorus (P) – 25.0; thiamine – 0.04; riboflavin – 0.02; niacin – 0.2; vitamin C – 4.0. In different varieties of carrots, the content of α-carotene is in the range of 530–35833 μg 100 g^{-1}, and the content of β-carotene is in the range of 1161–64350 μg 100 g^{-1} [23].

5.2.4 Table beet

Table beets contain folic acid and have a high concentration of betalain pigments, which are powerful antioxidants. Also, table beets contain the following nutrients (%) [24]: water – 87.4±0.3; fat – 0.3±0.1; protein – 1.35±0.2; carbohydrates – 7.59±0.4; crude fiber – 1.9±0.2; ash – 1.4±0.2. The total sugar content in table beets varies between 21.03–31.58 g kg^{-1} [25]. The mineral and vitamin content of table beets is as follows (mg 100 g^{-1}) [24]: sodium (Na) – 72.6; potassium (K) – 30.1; calcium (Ca) – 12.2; iron (Fe) – 0.75; zinc (Zn) – 0.21; copper (Cu) – 0.09; vitamin B_6 – 0.067; niacin – 0.334; vitamin C – 7.2.

5.2.5 Zucchini

The total sugar content of zucchini varies between 3.7–3.9 g 100 g^{-1}, in particular, fructose – 1.8–1.9 g 100 g^{-1}, glucose – 0.9–1.0 g 100 g^{-1}, sucrose – 0.9–1.1 g 100 g^{-1} [26]. The content of vitamin C in zucchini is in the range of 7.6–8.0 mg 100 g^{-1}, phenolic acids – 37.9–40.9 μg g^{-1}, flavonoids – 4.2–4.4 μg g^{-1} [26]. The mineral content of zucchini is as follows (mg 100 g^{-1} DW) [27]: potassium (K) – 2999.2–4660.0; calcium (Ca) – 243.7–359.0; iron (Fe) – 3.4–7.3; zinc (Zn) – 4.0–4.5; copper (Cu) – 0.36–0.90; phosphorus (P) – 541.2–600.0; magnesium (Mg) – 243.7–319.0; manganese (Mn) – 2.3–2.7.

5.2.6 Flax seeds

The chemical composition of flax seeds may vary depending on the characteristics of the variety and growing conditions. The chemical composition of flax seeds is as follows (%) [28]: water – 6.99±0.24 %; protein – 21.76±0.58 %; fat – 42.41±1.01 %; carbohydrates – 26.11±0.80 %; ash – 4.00±0.25 %. Flax seeds are also a source of dietary fiber (40 g 100 g^{-1}), α-linolenic acid (22.8 g 100 g^{-1}), linoleic acid (5.9 g 100 g^{-1}) and oleic acid (7.3 g 100 g^{-1}) [29]. The mineral and vitamin content of flax seeds is as follows (mg 100 g^{-1}) [29]: sodium (Na) – 27.0; potassium (K) – 831.0; calcium (Ca) – 236.0; iron (Fe) – 5.0; zinc (Zn) – 4.0; copper (Cu) – 1.0; phosphorus (P) – 622.0; magnesium (Mg) – 431.0; manganese (Mn) – 3.0; thiamine – 0.53; riboflavin – 0.23; niacin – 3.21; ascorbic acid – 0.50; pyridoxine – 0.61; pantothenic acid – 0.57; folic acid – 0.112. Due to its chemical composition, flaxseed is an important functional ingredient in the diet.

5.2.7 Freeze-dried vegetable and fruit-berry powders

To improve the colour, taste and nutritional value of foods, freeze-dried vegetable and fruit-berry powders are added to them as ingredients. The mineral content of freeze-dried plant powders (strawberry, raspberry, apricot, blackcurrant, pumpkin) is in the range of (mg 100 g^{-1}) [30]: sodium (Na) – 62.7–152.2; potassium (K) – 703.6–1610.7; calcium (Ca) – 124.3–223.3; iron (Fe) – 3.8–11.6; zinc (Zn) – 2.4–5.3; copper (Cu) – 34.0–464.1; phosphorus (P) – 115.7–340.1; magnesium (Mg) – 73.1–170.4; manganese (Mn) – 0.3–1.4. The content of phenolic compounds in freeze-dried plant powders (blueberry, raspberry, blackberry, pomegranate, table beet) is as follows (mg 100 g^{-1} DW) [31]: catechin – 10.09–35.41; epicatechin – 48.34–58.50; anthocyanins – 138.74–32933.63. Freeze-dried plant powders (carrot, beet, pumpkin, apple, raspberry, apricot) contain the following nutrients (%) [32]: protein – 3.2–9.2; fat – 0.0–1.0; carbohydrates – 52.3–73.0.

5.2.8 Chocolate

There are many types of chocolate (dark, milk, and white) with varying content of cocoa, cocoa butter, and milk. The nutritional composition of chocolate depends mainly on the cocoa content [33]:

– white chocolate (g 100 g^{-1}): protein – 5.87; fat – 32.1; carbohydrates – 59.2;

– milk chocolate (g 100 g^{-1}): protein – 7.65; fat – 29.7; carbohydrates – 59.4;

– dark chocolate with 45–59 % cocoa content (g 100 g^{-1}): protein – 4.88; fat – 31.3; carbohydrates – 61.2.

The level of minerals in different types of chocolate with different cocoa content varies widely:

– white chocolate (mg 100 g^{-1}) [33]: potassium (K) – 286; calcium (Ca) – 199; iron (Fe) – 0.24; zinc (Zn) – 0.45; phosphorus (P) – 176; magnesium (Mg) – 12; manganese (Mn) – 0.008; selenium (Se) – 0.0045;

– milk chocolate (mg 100 g^{-1}) [34]: sodium (Na) – 72.91±1.48; potassium (K) – 379.05±10.94; calcium (Ca) – 180.43±3.00; iron (Fe) – 1.19±0.03; zinc (Zn) – 0.94±0.04; copper (Cu) – 0.31±0.00; phosphorus (P) – 198.91±2.72; magnesium (Mg) – 52.28±2.03; manganese (Mn) – 0.31±0.00; selenium (Se) – 0.06±0.01;

– dark chocolate with 60–90 % cocoa content (mg 100 g^{-1}) [34]: sodium (Na) – 3.30–5.20; potassium (K) – 465.55–720.11; calcium (Ca) – 64.33–90.83; iron (Fe) – 9.73–11.24; zinc (Zn) – 2.24–3.52; copper (Cu) – 1.43–2.02; phosphorus (P) – 221.80–396.51; magnesium (Mg) – 158.78–252.21; manganese (Mn) – 1.65–2.05; selenium (Se) – 0.08–0.10.

The vitamin content of different types of chocolate is as follows (mg 100 g^{-1}) [33]:

– milk chocolate (mg 100 g^{-1}): thiamine – 0.112; riboflavin – 0.298; niacin – 0.386; vitamin E – 0.51;

– dark chocolate with 45–59 % cocoa content (mg 100 g^{-1}): thiamine – 0.025; riboflavin – 0.05; niacin – 0.725; vitamin E – 0.54;

– white chocolate (mg 100 g^{-1}): thiamine – 0.063; riboflavin – 0.282; niacin – 0.745; vitamin E – 0.96.

Milk chocolate contains between 0.05 % and 0.17 % caffeine, while dark chocolate contains between 0.23 % and 0.31 % [35].

5.3 Materials and methods

5.3.1 Materials and laboratory equipment

The developed compositions of multilayer fruit and vegetable chips containing apples, carrots, pears, table beets, zucchini, flax seeds, chocolate (dark, milk, and white), freeze-dried plant powders (mango, bilberry, strawberry, blueberry, raspberry, currant) were examined. Fruits, vegetables, freeze-dried plant powders, flax seeds, and chocolate were purchased from a local supermarket (Lutsk, Ukraine). The cocoa content in the chocolate (chocolate chips) was as follows: white chocolate – 31 %; milk chocolate – 38 %; dark chocolate – 70.5 %. Samples of multilayer chips and multilayer glazed chips were prepared according to the developed technologies.

During the study, the following laboratory equipment was used: GORENJE Slicer R 506 E; Morphy Richards Intellisteam Food Steamer 470006; Dehydrator Excalibur 4926T Black; Hamilton Beach Fresh Grind Electric Coffee Grinder; Esperanza Electric Hot Plate EKH008; Laboratory Drying Cabinet SNOL-250/350; Thermometer Testo 405V1; Laboratory Balances FEN-V2003; IRAffinity-1S Spectrometer. The study was conducted in the laboratory of the Lutsk National Technical University (Ukraine).

5.3.2 Methods

5.3.2.1 Moisture content and nutritional value determination

Moisture content of samples of multilayer chips was determined by standard method (AOAC Official Method) [36]. The moisture content of dried multilayer chips of all compositions (without glaze) ranged from 6.0 % to 8.0 %.

The protein, fat and carbohydrate contents were determined by the methods described in [37].

The determination of the mineral content of the developed chips consisted of two steps. In the first step, the determination of mineral content in samples of dried apple, carrot, pear, table beet, zucchini, and flax seeds, chocolate (dark, milk, and white), freeze-dried powders (mango, bilberry, strawberry, blueberry, raspberry, currant) was carried out by the technique of analysis by spectrophotometry plasma emission [34]. In the second step, the mineral content of the chips was determined by calculation, taking into account the mineral content of the dried components of the chips and their ratio in the finished product.

5.3.2.2 Sensory analysis and quality evaluation method

The sensory properties (appearance, colour, taste, smell and consistency) of multilayer chips and multilayer glazed chips were evaluated by experts according to the methodology [38] on a five-point scale (5 points – the quality is excellent; 4 points – the quality is good; 3 points – the quality is satisfactory; 2 points – the quality is poor (barely acceptable); 1 point – the quality is very poor). In addition to scoring the sensory properties of compositions of multilayer chips and multilayer glazed chips, experts gave their verbal description.

The weighting coefficients of the sensory properties of the examined multilayer chips were determined by the ranking method based on the results of an expert survey. The quality index Q of the samples of multilayer chips and multilayer glazed chips were determined by the expert method [38] and calculated by the Equation:

$$Q = \sum_{i=1}^{n} \frac{m_i q_i}{q_{bi}}, \quad (5.1)$$

where m_i is the weighting coefficient of the sensory properties of multilayer chips and multilayer glazed chips; q_i is the mean value of the sensory property of multilayer chips and multilayer glazed chips (points); q_{bi} is the base value of the sensory property of multilayer chips and multilayer glazed chips (for all sensory properties the base value is 5 points).

5.3.2.3 Determination of the colour of the multilayer glazed chips

The colour of the multilayer glazed chips was determined using the camera of the Xiaomi Redmi Note 8 Pro smartphone (China) and the Color Detector & Catcher mobile application, using the RGB additive colour model. The colour of multilayer chips was not determined because different layers of chips had different colours, which is characteristic of the colours of dried raw materials.

5.3.2.4 Calorie content determination

The calorie content of multilayer chips and multilayer glazed chips was calculated by the Equation:

$$E = 4P + 9F + 3.75C, \qquad (5.2)$$

where E is calorie content (kcal 100 g^{-1}); 4, 9, 3.75 are calories per 1 g of protein, fat, and carbohydrate, respectively (kcal); P, F, C are the mean amounts of protein, fat and carbohydrates, respectively, per 100 g of multilayer chips and multilayer glazed chips (g 100 g^{-1}).

5.3.2.5 Statistical analysis and calculations

All data reported as mean ± standard deviation (SD). Statistical analysis and calculations were conducted using the Mathcad 14 software.

5.4 Technologies of multilayer and glazed fruit and vegetable chips

The technology of multilayer fruit and vegetable chips is shown in **Fig. 5.1**. In order to separate the damaged and spoiled fruits, they are sorted. High quality, ripe fruits and vegetables are washed and peeled as needed. For the base layer of chips, washed vegetables or fruits are sliced into 2–3 mm thick slices. During calibration, small and damaged slices are separated. Solid slices are blanched in steam at a temperature of 85–95 °C for 120–180 s.

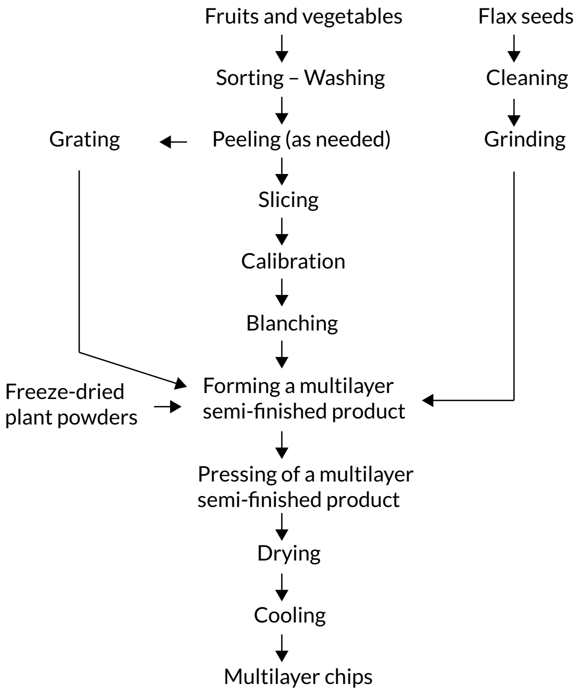

Fig. 5.1 Flowchart of technology of multilayer fruit and vegetable chips

Flax seeds are cleaned to remove impurities and ground to a fraction size of less than 2 mm. Some fresh fruits and vegetables are grated after washing. After the preparation of plant raw materials, multilayer semi-finished products are formed. For this reason, blanched slices of fruits and vegetables are breaded on one side in freeze-dried plant powder or powder mixture, and also breaded in crushed flax seeds. Over the layer of crushed flax seeds, a 2–3 mm thick layer of grated fruit or vegetables or both is formed. The formed multilayer semi-finished product is pressed and dried at a temperature of 63–70 °C to a moisture content of 5–8 %. The drying time can be 6–10 hours, depending on the plant raw material and its initial moisture content. In this regime of hot air drying, the useful substances contained in the plant raw materials are preserved with the minimum loss in the finished product. Increasing the temperature of air drying causes an increase in the loss of nutrients and deterioration of the quality of the dried product, especially the quality of dried plant products deteriorates at a drying temperature of 80–95 °C [39]. Dried multilayer chips are cooled. Multilayer fruit and vegetable chips must be stored in a closed package at an air temperature of 0–20 °C and an air humidity of 75 % or less.

The technology of chocolate-glazed multilayer chips with freeze-dried plant powder or powder mixture is shown in **Fig. 5.2**.

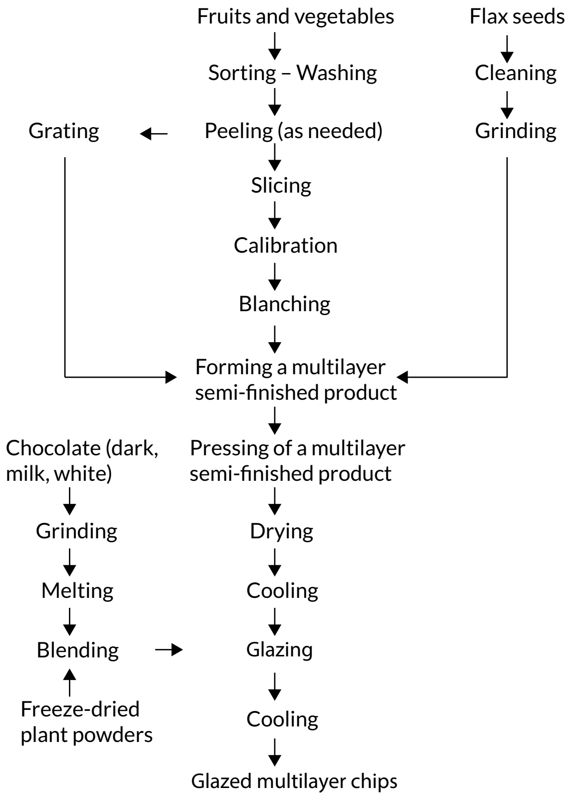

Fig. 5.2 Flowchart of technology of glazed multilayer fruit and vegetable chips

The preparation of plant raw materials is similar to the technology of multilayer chips. Blanched fruit and vegetable slices are breaded on one side in crushed flax seeds. Then, a 2–3 mm thick layer of grated vegetables and fruits is formed over the layer of crushed flax seeds. The multilayer semi-finished product is pressed and dried at a temperature of 63–70 °C to a moisture content of 5–8 %. The dried multilayer semi-finished product is cooled.

Chocolate (white, dark, milk) is ground and melted. Freeze-dried plant powder or a powder mixture is blended with melted chocolate. The content of freeze-dried plant powder in the chocolate glaze does not exceed 10 %. The cooled semi-finished product is glazed on both sides in chocolate mass with plant powder. Chopped nuts may be sprinkled on both sides of the multilayer glazed chips. The finished product is cooled to the temperature of 15–20 °C. The storage conditions for chocolate-glazed multilayer chips are the same as for unglazed chips.

5.5 Characteristic of multilayer fruit and vegetable chips

5.5.1 Sensory properties of multilayer fruit and vegetable chips

The developed multilayer fruit and vegetable chips are shown in **Fig. 5.3** (samples of chips are marked as follows: A – solid apple slice; P – solid pear slice; T – solid table beet slice; Ma – mango powder; F – crushed flax seeds; Ag – grated apple; C – grated carrot; Pu – grated pumpkin; B – bilberry powder; Bl – blueberry powder; R – raspberry powder; S – strawberry powder). The appearance of the samples from the base layer side and their cross-section are also shown in **Fig. 5.4**. The base layer of the multilayer chips was a solid slice of apple, pear or table beet. Freeze-dried powders of mango, strawberry, bilberry, blueberry and raspberry were used to bread blanched apple, pear and table beet slices. The apple, pear and table beet slices were also breaded on one side with crushed flax seeds. Grated apple, carrot and pumpkin were used for the top layer of the multilayer chips.

The main sensory indicators of multilayer fruit and vegetable chips are appearance, colour, taste, smell and consistency. The results of the expert evaluation of the sensory properties of multilayer fruit and vegetable chips on a five-point scale are presented in **Table 5.1**.

Multilayer chips had different shapes. The shape of the chips depended on the fruits and vegetables used for the base layer of the chips and the direction in which they were cut. Some multilayer chips had a hole in the central part from the cut core of a fruit containing seeds or pips (e. g. apples, pears). As a result of drying, the base layer of the chips was deformed, resulting in a wavy surface of the finished product.

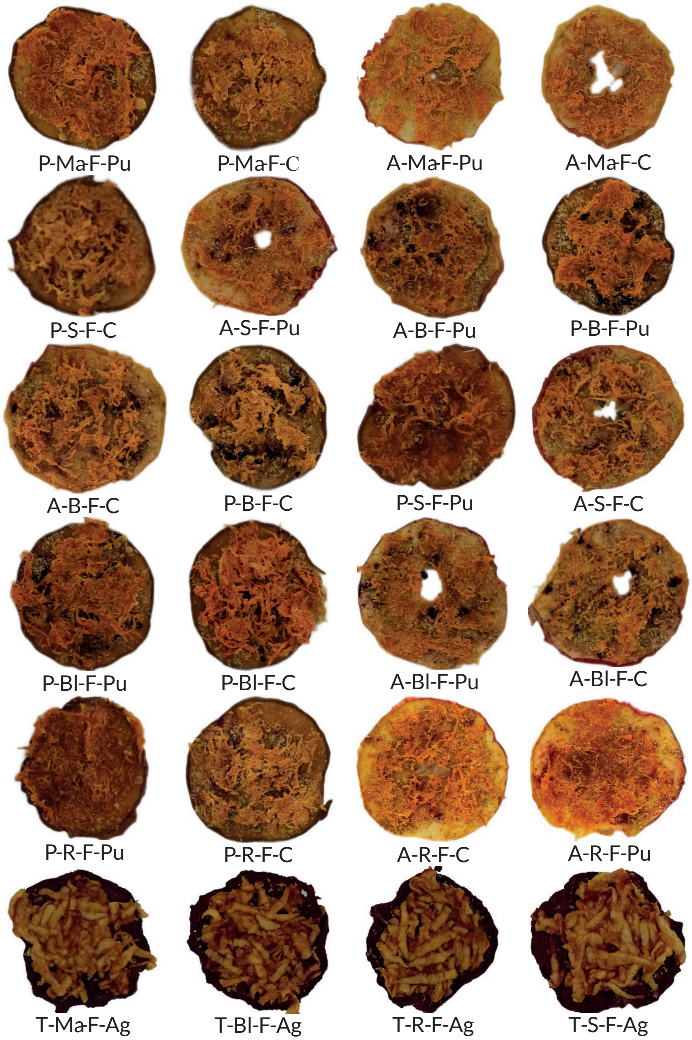

Fig. 5.3 Samples of multilayer fruit and vegetable chips

The surface of multilayer chips from the base layer side was typical of dried vegetable and fruit slices. Due to added layers of crushed flax seeds and grated vegetables or fruits, the surface of multilayer chips was uneven. The appearance of multilayer chips A-R-F-C (4.86±0.35), P-Ma-F-Pu and A-R-F-Pu (4.71±0.45) was rated the highest. And the appearance of the P-B-F-C composition was rated the lowest (3.43±0.50).

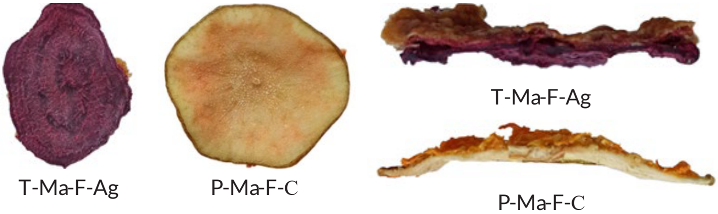

Fig. 5.4 The appearance of the samples from the base layer side and their cross-section

The colour of the multilayer chips was similar to the colour of dried vegetables and fruits, mostly different shades of yellow and brown. Multilayer chips with a pear base layer were darker in colour than chips with an apple base layer. The table beet base of the chips was dark maroon with a light brown apple layer. The addition of freeze-dried plant powders significantly affected the colour of the chips. Bilberry and blueberry powders, which have a burgundy colour, caused the multilayer chips to have unsightly dark spots. Freeze-dried mango powder was not visible on the surface of the multilayer chips because it took on the colour of dried fruits and vegetables after drying. Strawberry and raspberry powders caused dark brown spots on the surface of the chips after drying. Crushed flax seeds, which were brown in colour, was also visible on the surface of the multilayer chips. No plant powders were visible on the beetroot-based chips. Developed chips with a base layer of apple and freeze-dried mango powder received high scores (4.57–4.71) because they had an attractive colour of traditional chips. The P-B-F-C and P-Bl-F-Pu compositions of chips received the lowest score (2.86±0.35).

Multilayer chips tasted like the dried fruits, berries, and vegetables used in the recipe. Developed chips had dried fruit and berry smell. Apple-based chips with blueberry and bilberry powders had a sour taste. Pear-based multilayer chips had a sweet taste. All beet-based chips tasted like table beets. The taste of freeze-dried mango powder was not noticeable in the chips. Instead, strawberry and raspberry powders gave the multilayer chips a pleasant taste and smell of these berries. There was also an aftertaste of flax seeds, dried carrot and pumpkin. Multilayer chips with an apple base layer scored higher than those with a pear base layer.

The A-S-F-Pu composition received the highest score (4.86±0.35) for taste. According to the experts, P-Ma-F-C multilayer chips had the least pleasant taste (3.71±0.45). Two compositions (A-S-F-C and A-R-F-Pu) received the highest score (5.00±0.00) for smell.

The consistency of all compositions of multilayer chips was crispy and brittle, i. e. similar to traditional chips. This consistency is due to the moisture content of the multilayer chips of 6–8 %. The consistency of the developed chips was rated by experts with high scores of 4.29–4.86. A special feature of multilayer chips is the feeling of crushed flax seeds in the mouth.

Table 5.1 Evaluation of the sensory properties of multilayer chips

Multilayer chips	Appearance	Colour	Taste	Smell	Consistency
P-Ma-F-Pu	4.71±0.45	4.14±0.35	3.86±0.35	4.00±0.00	4.57±0.50
P-Ma-F-C	4.57±0.50	4.00±0.00	3.71±0.45	4.00±0.00	4.43±0.50
A-Ma-F-Pu	4.43±0.50	4.57±0.50	4.14±0.35	4.14±0.35	4.71±0.45
A-Ma-F-C	4.29±0.45	4.57±0.50	4.00±0.00	4.14±0.35	4.71±0.45
P-S-F-C	4.14±0.35	4.14±0.35	4.43±0.50	4.57±0.50	4.29±0.45
A-S-F-Pu	4.29±0.45	4.29±0.45	4.86±0.35	4.57±0.50	4.43±0.50
A-B-F-Pu	3.86±0.35	3.71±0.45	4.00±0.00	4.14±0.35	4.57±0.50
P-B-F-Pu	3.57±0.50	3.57±0.50	4.00±0.00	4.00±0.00	4.43±0.50
A-B-F-C	3.86±0.35	3.57±0.50	4.29±0.45	4.29±0.45	4.43±0.50
P-B-F-C	3.43±0.50	2.86±0.35	3.86±0.35	4.00±0.45	4.57±0.50
P-S-F-Pu	3.86±0.35	3.00±0.00	4.43±0.50	4.86±0.35	4.43±0.50
A-S-F-C	4.14±0.35	3.71±0.45	4.71±0.45	5.00±0.00	4.71±0.45
P-Bl-F-Pu	3.57±0.50	2.86±0.35	4.00±0.00	4.29±0.45	4.43±0.50
P-Bl-F-C	3.71±0.45	3.00±0.35	4.00±0.00	4.29±0.45	4.43±0.50
A-Bl-F-Pu	4.00±0.00	3.86±0.35	4.29±0.45	4.57±0.50	4.86±0.35
A-Bl-F-C	3.71±0.45	3.86±0.35	4.14±0.35	4.57±0.50	4.86±0.35
P-R-F-Pu	4.29±0.45	3.14±0.35	4.29±0.45	4.71±0.45	4.43±0.50
P-R-F-C	4.43±0.50	3.71±0.45	4.29±0.45	4.71±0.45	4.29±0.45
A-R-F-C	4.86±0.35	4.71±0.45	4.57±0.50	4.86±0.35	4.86±0.35
A-R-F-Pu	4.71±0.45	4.57±0.50	4.71±0.45	5.00±0.00	4.86±0.35
T-Ma-F-Ag	3.86±0.35	3.71±0.45	4.14±0.35	4.71±0.45	4.71±0.45
T-Bl-F-Ag	3.86±0.35	3.71±0.45	4.71±0.45	4.71±0.45	4.71±0.45
T-R-F-Ag	3.86±0.35	3.71±0.45	4.71±0.45	4.86±0.35	4.71±0.45
T-S-F-Ag	3.86±0.35	3.71±0.45	4.43±0.50	4.86±0.35	4.71±0.45

In order to generalise the results of the sensory analysis of the developed multilayer chips, the quality index of chips *Q* was calculated (**Table 5.2**). To calculate the quality index, the weighting coefficients of the sensory properties of chips were determined as follows: appearance – m_1=0.24; colour – m_2=0.15; taste – m_3=0.30; smell – m_4=0.11; consistency – m_5=0.20.

Among the multilayer chips with a pear base layer, the P-S-F-C composition obtained the highest value of the quality index (*Q*=0.861), and the lowest value – P-B-F-C (*Q*=0.753). Among the chips with an apple base layer, the A-R-F-Pu composition received the highest value of the quality index (*Q*=0.950). The T-R-F-Ag composition was rated the highest (*Q*=0.875) among beet-based chips. The following multilayer chips also obtained a high-quality index: A-S-F-Pu – *Q*=0.904; A-R-F-C – *Q*=0.920. Among the apple-based chips, the A-B-F-Pu composition had the lowest quality index (*Q*=0.810).

Table 5.2 Quality index of multilayer chips

Multilayer chips	Quality index *Q*	Multilayer chips	Quality index *Q*
P-Ma-F-Pu	0.853	P-S-F-Pu	0.825
P-Ma-F-C	0.827	A-S-F-C	0.891
A-Ma-F-Pu	0.878	P-Bl-F-Pu	0.769
A-Ma-F-C	0.863	P-Bl-F-C	0.780
P-S-F-C	0.861	A-Bl-F-Pu	0.860
A-S-F-Pu	0.904	A-Bl-F-C	0.837
A-B-F-Pu	0.810	P-R-F-Pu	0.838
P-B-F-Pu	0.784	P-R-F-C	0.857
A-B-F-C	0.821	A-R-F-C	0.920
P-B-F-C	0.753	A-R-F-Pu	0.950
T-Ma-F-Ag	0.837	T-R-F-Ag	0.875
T-Bl-F-Ag	0.871	T-S-F-Ag	0.858

5.5.2 Nutritional value and calorie content of multilayer fruit and vegetable chips

The nutritional value and calorie content of multilayer fruit and vegetable chips are presented in **Table 5.3**. The nutrient content of multilayer chips depended on their composition. It was found to be in the range of (g 100 g^{-1}): protein – 5.77–9.12; fat – 8.32–8.66; carbohydrates – 37.42–53.92. Beet chips had the highest protein content (8.95–9.12 g 100 g^{-1}). Multilayer chips with grated carrot had a higher protein content than chips with grated pumpkin, when other ingredients were equal. Chips with mango and strawberry powders had lower protein content than those with blueberry, bilberry, and raspberry powders. The addition of freeze-dried blueberry powder and pumpkin to the recipe of multilayer chips resulted in a decrease in the fat content compared to other ingredient combinations. However, the fat content of chips with different combinations of plant-based ingredients varied slightly. The T-R-F-Ag composition had the highest fat content (8.66 g 100 g^{-1}). Flax seeds are a source of protein and fat, so adding it to chips can increase the amount of these nutrients in the finished product. Carbohydrate content decreased in multilayer chips with the addition of freeze-dried blueberry powder compared to other freeze-dried plant powders. Multilayer chips with grated carrot had a higher carbohydrate content than chips with grated pumpkin.

The calorie content of multilayer fruit and vegetable chips varied between 238.9 and 312.0 kcal 100 g^{-1}. Multilayer chips containing grated carrot had more calories than those containing grated pumpkin. The T-R-F-Ag composition had the highest calorie content (312.0 kcal 100 g^{-1}). Chips containing pear, blueberry powder, crushed flax seeds and grated pumpkin had the lowest calories (238.9 kcal 100 g^{-1}).

Table 5.4 shows the mineral content of multilayer chips. The mineral content of the chips varied as follows (mg 100 g^{-1}): iron (Fe) – 1.58–4.51; magnesium (Mg) – 105.34–139.36; calcium (Ca) – 64.57–107.41; potassium (K) – 447.53–769.71. The highest iron content (4.51 mg 100 g^{-1}) was in the A-S-F-C composition. Chips containing apple and carrot had the highest iron content, while samples containing pear and pumpkin had the lowest. The strawberry powder enriched the chips with iron more than the other powders used. The T-S-F-Ag composition had the highest magnesium content (139.36 mg 100 g^{-1}). Compositions of chips containing apple and carrot had higher magnesium content than samples containing combinations of such raw materials: apple-pumpkin, pear-pumpkin, pear-carrot. The addition of raspberry and strawberry powders fortified the chips with magnesium. The A-R-F-C composition had the highest calcium content (107.41 mg 100 g^{-1}). Compositions of multilayer chips containing carrot had a higher calcium content than those containing other ingredients. The highest calcium enrichment of chips was found when raspberry powder was added. The highest potassium content (769.71 mg 100 g^{-1}) was found in the A-R-F-C composition of chips. Samples containing carrot had the highest potassium content. The addition of raspberry powder fortified the chips with potassium more than the addition of other freeze-dried plant powders.

Table 5.3 Nutritional value and calorie content of multilayer chips

Multilayer chips	Protein, g 100 g^{-1}	Fat, g 100 g^{-1}	Carbohydrates, g 100 g^{-1}	Calorie content, kcal 100 g^{-1}
P-Ma-F-Pu	5.77±0.24	8.39±0.14	38.90±0.98	244.4
P-Ma-F-C	7.57±0.31	8.48±0.16	53.42±1.21	306.9
A-Ma-F-Pu	5.77±0.21	8.39±0.16	37.85±0.87	240.5
A-Ma-F-C	7.57±0.26	8.48±0.13	52.37±1.13	302.9
P-S-F-C	7.58±0.26	8.49±0.15	53.37±1.15	306.8
A-S-F-Pu	5.78±0.22	8.40±0.15	39.30±0.96	246.1
A-B-F-Pu	5.92±0.19	8.38±0.18	39.40±0.94	246.8
P-B-F-Pu	5.92±0.21	8.38±0.15	38.95±1.01	245.1
A-B-F-C	7.72±0.30	8.47±0.14	53.92±1.17	309.3
P-B-F-C	7.72±0.29	8.47±0.16	53.47±1.22	307.6
P-S-F-Pu	5.78±0.18	8.40±0.16	38.85±0.95	244.4
A-S-F-C	7.58±0.24	8.49±0.13	53.82±1.14	308.5
P-Bl-F-Pu	5.94±0.20	8.32±0.10	37.42±1.03	238.9
P-Bl-F-C	7.74±0.27	8.41±0.16	51.94±1.17	301.4
A-Bl-F-Pu	5.94±0.18	8.32±0.12	37.87±1.00	240.6
A-Bl-F-C	7.74±0.25	8.41±0.15	52.39±1.19	303.0
P-R-F-Pu	5.93±0.19	8.49±0.15	38.58±0.92	244.8
P-R-F-C	7.73±0.25	8.58±0.16	53.10±1.15	307.3
A-R-F-C	7.73±0.28	8.58±0.14	53.55±1.18	309.0
A-R-F-Pu	5.93±0.17	8.49±0.15	39.03±1.03	246.5
T-Ma-F-Ag	8.95±0.11	8.55±0.12	53.04±1.06	311.6
T-Bl-F-Ag	9.12±0.14	8.48±0.16	51.56±1.12	306.1
T-R-F-Ag	9.11±0.12	8.66±0.09	52.72±1.00	312.0
T-S-F-Ag	8.96±0.07	8.57±0.06	52.99±1.08	311.6

Table 5.4 Mineral content of multilayer chips

Multilayer chips	Mineral content, mg 100 g^{-1}			
	Fe	Mg	Ca	K
P-Ma-F-Pu	1.69	108.09	64.57	468.58
P-Ma-F-C	2.41	120.09	85.78	697.48
A-Ma-F-Pu	3.45	114.89	82.39	521.09
A-Ma-F-C	4.17	126.89	103.60	750.00
P-S-F-C	2.76	120.70	100.94	709.06
A-S-F-Pu	3.79	115.49	84.23	532.67
A-B-F-Pu	3.49	113.46	82.33	511.26
P-B-F-Pu	1.73	106.66	77.83	458.75
A-B-F-C	4.21	125.46	103.54	740.16
P-B-F-C	2.45	118.66	99.04	687.65
P-S-F-Pu	2.04	108.70	100.94	480.16
A-S-F-C	4.51	127.49	105.44	761.57
P-Bl-F-Pu	1.58	105.34	74.31	447.53
P-Bl-F-C	2.30	117.34	95.52	676.43
A-Bl-F-Pu	3.33	112.14	78.81	500.04
A-Bl-F-C	4.05	124.14	100.02	728.94
P-R-F-Pu	1.73	110.92	81.70	488.30
P-R-F-C	2.45	122.92	102.91	717.20
A-R-F-C	4.21	129.71	107.41	769.71
A-R-F-Pu	3.49	117.71	86.20	540.81
T-Ma-F-Ag	3.19	117.39	81.64	496.72
T-Bl-F-Ag	3.07	114.64	78.06	475.67
T-R-F-Ag	3.23	136.00	85.45	516.44
T-S-F-Ag	3.53	139.36	83.48	508.30

5.6 Characteristic of multilayer glazed fruit and vegetable chips

5.6.1 Sensory properties of multilayer glazed fruit and vegetable chips

The multilayer glazed fruit and vegetable chips are shown in **Fig. 5.5** (samples of glazed chips are marked as follows: A – solid apple slice; T – solid table beet slice; Z – solid zucchini slice; F – crushed flax seeds; Ag – grated apple; C – grated carrot; D – dark chocolate; M – milk chocolate; W – white chocolate; Cu – currant powder). **Fig. 5.6** shows the appearance of the A-F-C-D-Cu sample from the base layer side and its cross-section. The base layer of the multilayer glazed chips was a solid slice of apple, table beet or zucchini. The apple, table beet and zucchini slices were breaded on one side with crushed flax seeds. Grated apple and carrot were used to form the layer over crushed flax seeds. Different types of chocolate (dark, milk, and white) and freeze-dried currant powder were used to prepare the glaze for the multilayer chips.

The results of the expert evaluation of the sensory properties of multilayer glazed chips are presented in **Table 5.5**. **Table 5.6** shows the results of determining the colour of multilayer glazed chips using the RGB additive colour model.

The shape and size of the multilayer chocolate-glazed chips depended on the shape and size of the fruits and vegetables used for the base layer of the chips. On the side of the base layer, the multilayer glazed chips had a smooth, wavy surface covered by the chocolate glaze. On the opposite side, the glazed chips had a bumpy surface that was the result of applying a glaze to a layer of grated fruit or vegetable. Some samples of chips had cracks in the glaze (e. g. A-F-C-D and A-F-Ag-D samples). On the side of the grated fruit and vegetable layer, small localized areas of the chips were not completely covered by the glaze. To eliminate these defects, it is necessary to grate the fruits and vegetables finer for the top layer of multilayer chips and also to make this layer thinner. The inner fruit and vegetable layers of all samples of glazed chips were not crisp and brittle. The glaze crumbled when the chips were cut and became sticky where the chips were held by the fingers [40].

The appearance, colour, taste and smell of the multilayer glazed chips depended on the combination of ingredients: vegetables, fruits, plant powders and chocolate. The sensory properties of the multilayer chips with glaze containing white chocolate and freeze-dried currant powder were rated higher (appearance – 3.29–4.71; colour – 3.29–4.71; taste – 4.29–4.71; smell – 4.00–4.71) than those of the chips with glaze containing white chocolate only (appearance – 3.00–3.29; colour – 3.00–3.71; taste – 3.29–4.29; smell – 4.00–4.71). The addition of currant powder to the white chocolate glaze did not significantly affect the smell rating of the chips. Glaze with white chocolate and currant powder made the appearance of the chips more attractive.

Fig. 5.5 Samples of multilayer glazed fruit and vegetable chips [40]

A-F-C-D-Cu A-F-C-D-Cu

Fig. 5.6 The appearance of the A-F-C-D-Cu sample from the base layer side and its cross-section

The berry powder gave the white chocolate glaze a sweet-sour flavor that harmonized with the flavor of the dried vegetables and fruits. The sensory properties of multilayer glazed chips with an apple had higher scores than the sensory properties of the chips with zucchini. The consistency of the white chocolate glazed chips ranged from 1.71 to 3.00 points. Such low scores are due to the fact that the glazed multilayer chips did not have a crisp consistency.

Milk chocolate glazed chips had the following sensory property scores: appearance – 3.71–4.00; colour – 3.29–4.00; taste – 3.29–4.71; smell – 4.00–4.29; consistency – 1.29–2.00. The sensory properties of the multilayer glazed chips were improved by adding currant powder to the milk chocolate glaze as follows: appearance – 4.29–5.00; colour – 4.00–4.71; taste – 3.71–5.00; smell – 4.00–4.71. The consistency scores of the chips continued to be low (1.29–3.00). Milk chocolate glazed multilayer chips were light brown, while those glazed with milk chocolate glaze with currant powder were dark brown. Milk chocolate glazed chips had a sweet chocolate taste with a hint of the vegetable or fruit used. And milk chocolate glazed chips with currant powder had a sweet and sour taste, but the chocolate taste was dominant. All samples of the milk chocolate glazed chips had a slight chocolate flavor.

The appearance of the dark chocolate glazed chips with currant powder was rated from 4.71 to 5.00 points, and the appearance of the dark chocolate glazed chips was rated from 4.29 to 5.00 points. The colour of chips glazed with dark chocolate was dark brown, it was rated from 4.29 to 5.00 points. When currant powder was added, the colour of the chips became darker. The dark chocolate glazed chips had a bitter taste of dark chocolate. Adding currant powder to the glaze gave the chips a sour taste. The glazed beet chips had a beet aftertaste. The taste score of dark chocolate glazed chips ranged from 3.29 to 5.00. In addition, chips containing an apple had the highest score 5.0±0.00. Adding freeze-dried currant powder to the dark chocolate glaze did not affect the smell of the chips, they all had a light chocolate smell. The smell of chips with dark chocolate glaze was estimated at 3.71–4.71 points. The consistency of the dark chocolate-covered chips was estimated at 1.71–3.00 points.

Table 5.5 Evaluation of the sensory properties of multilayer glazed chips [40]

Multilayer glazed chips	Appearance	Colour	Taste	Smell	Consistency
Z-F-Ag-W	3.29±0.45	3.29±0.45	4.00±0.00	4.00±0.00	2.00±0.00
Z-F-Ag-M	4.00±0.00	4.00±0.00	4.00±0.00	4.00±0.00	2.00±0.00
Z-F-Ag-D	4.71±0.45	4.71±0.45	3.71±0.45	4.00±0.00	2.29±0.45
Z-F-Ag-W-Cu	4.29±0.45	4.29±0.45	4.71±0.45	4.00±0.00	2.00±0.00
Z-F-Ag-M-Cu	4.71±0.45	4.71±0.45	4.71±0.45	4.00±0.00	2.00±0.00
Z-F-Ag-D-Cu	4.71±0.45	4.71±0.45	4.71±0.45	4.00±0.00	2.29±0.45
Z-F-C-W	3.29±0.45	3.71±0.45	3.29±0.45	4.00±0.00	2.00±0.00
Z-F-C-M	3.71±0.45	3.29±0.45	3.29±0.45	4.00±0.00	2.00±0.00
Z-F-C-D	4.29±0.45	4.29±0.45	3.29±0.45	3.71±0.45	2.29±0.45
Z-F-C-W-Cu	4.29±0.45	4.29±0.45	4.29±0.45	4.29±0.45	2.00±0.00
Z-F-C-M-Cu	4.29±0.45	4.00±0.00	3.71±0.45	4.00±0.00	2.00±0.00
Z-F-C-D-Cu	4.71±0.45	4.71±0.45	4.29±0.45	3.71±0.45	2.29±0.45
A-F-C-W	3.00±0.00	3.29±0.45	4.29±0.45	4.29±0.45	2.00±0.00
A-F-C-M	3.71±0.45	3.29±0.45	4.29±0.45	4.29±0.45	1.71±0.45
A-F-C-D	5.00±0.00	5.00±0.00	4.00±0.00	4.71±0.45	2.29±0.45
A-F-C-W-Cu	4.71±0.45	4.71±0.45	4.71±0.45	4.71±0.45	2.00±0.00
A-F-C-M-Cu	4.71±0.45	4.71±0.45	5.00±0.00	4.29±0.45	1.71±0.45
A-F-C-D-Cu	5.00±0.00	5.00±0.00	3.71±0.45	4.71±0.45	2.29±0.45
A-F-Ag-W	3.29±0.45	3.00±0.00	4.29±0.45	4.71±0.45	1.71±0.45
A-F-Ag-M	4.00±0.00	3.71±0.45	4.71±0.45	4.29±0.45	1.29±0.45
A-F-Ag-D	5.00±0.00	5.00±0.00	4.71±0.45	4.71±0.45	2.00±0.00
A-F-Ag-W-Cu	4.00±0.00	4.29±0.45	4.71±0.45	4.71±0.45	1.71±0.45
A-F-Ag-M-Cu	5.00±0.00	4.71±0.45	5.00±0.00	4.71±0.45	1.29±0.45
A-F-Ag-D-Cu	5.00±0.00	5.00±0.00	5.00±0.00	4.71±0.45	1.71±0.45
T-F-Ag-D	5.00±0.00	5.00±0.00	4.00±0.00	4.71±0.45	3.00±0.00
T-F-Ag-D-Cu	5.00±0.00	4.71±0.45	4.29±0.45	4.71±0.45	3.00±0.00
T-F-Ag-W-Cu	3.29±0.45	3.29±0.45	4.29±0.45	4.71±0.45	3.00±0.00
T-F-Ag-M-Cu	4.71±0.45	4.71±0.45	4.29±0.45	4.71±0.45	3.00±0.00

Table 5.6 Colour of multilayer glazed chips

Multilayer glazed chips	RGB colours	Multilayer glazed chips	RGB colours
Z-F-Ag-W	133, 78, 43	A-F-C-W	152, 124, 112* 181, 81, 31**
Z-F-Ag-M	89, 50, 30	A-F-C-M	86, 46, 42* 107, 32, 15**
Z-F-Ag-D	36, 14, 3	A-F-C-D	54, 34, 30
Z-F-Ag-W-Cu	68, 37, 39	A-F-C-W-Cu	120, 86, 80* 181, 81, 31**
Z-F-Ag-M-Cu	47, 23, 24	A-F-C-M-Cu	77, 35, 25
Z-F-Ag-D-Cu	33, 25, 27	A-F-C-D-Cu	56, 33, 27
Z-F-C-W	156, 112, 79* 181, 81, 31**	A-F-Ag-W	178, 142, 94
Z-F-C-M	68, 29, 18* 107, 41, 31**	A-F-Ag-M	101, 46, 29
Z-F-C-D	43, 32, 33	A-F-Ag-D	48, 27, 23
Z-F-C-W-Cu	121, 87, 82* 181, 81, 31**	A-F-Ag-W-Cu	102, 73, 67
Z-F-C-M-Cu	50, 25, 20	A-F-Ag-M-Cu	77, 36, 27
Z-F-C-D-Cu	27, 19, 24	A-F-Ag-D-Cu	33, 13, 13
T-F-Ag-D	64, 39, 33	T-F-Ag-W-Cu	176, 137, 120
T-F-Ag-D-Cu	64, 39, 35	T-F-Ag-M-Cu	87, 42, 25

*Note: *main colour; **colour of the carrot visible under the glaze*

The weighting coefficients of the sensory properties of multilayer chocolate glazed chips, which were used to calculate the quality index, were determined as follows [40]: appearance – m_1=0.25; colour – m_2=0.15; taste – m_3=0.33; smell – m_4=0.11; consistency – m_5=0.16. The calculated quality index of the multilayer chocolate glazed chips is shown in **Table 5.7**.

Compositions of multilayer chips containing chocolate glaze with freeze-dried currant powder had a higher value of the quality index than chips where the glaze did not contain currant powder. The exception was the A-F-C-D-Cu composition with a quality index Q=0.822, since the A-F-C-D composition had a lower quality index Q=0.842. The A-F-C-W-Cu composition had the highest quality index value (Q=0.854) among the chips with white chocolate. The quality index of the milk chocolate-covered chips ranged from 0.654 to 0.866, with the A-F-Ag-M-Cu composition (*Q*=0.866) having the highest value (*Q*=0.866). The quality index of the multilayer chips with dark chocolate varied within 0.716–0.888. The A-F-Ag-D-Cu composition had the highest value of the quality index Q=0.888. Therefore, the dark chocolate glazed chips had the highest quality indices.

Table 5.7 Quality index of multilayer glazed chips [40]

Multilayer glazed chips	Quality index *Q*	Multilayer glazed chips	Quality index Q
Z-F-Ag-W	0.700	A-F-C-W	0.692
Z-F-Ag-M	0.736	A-F-C-M	0.716
Z-F-Ag-D	0.782	A-F-C-D	0.842
Z-F-Ag-W-Cu	0.806	A-F-C-W-Cu	0.854
Z-F-Ag-M-Cu	0.838	A-F-C-M-Cu	0.856
Z-F-Ag-D-Cu	0.848	A-F-C-D-Cu	0.822
Z-F-C-W	0.646	A-F-Ag-W	0.696
Z-F-C-M	0.654	A-F-Ag-M	0.758
Z-F-C-D	0.716	A-F-Ag-D	0.878
Z-F-C-W-Cu	0.786	A-F-Ag-W-Cu	0.798
Z-F-C-M-Cu	0.732	A-F-Ag-M-Cu	0.866
Z-F-C-D-Cu	0.814	A-F-Ag-D-Cu	0.888
T-F-Ag-D	0.864	T-F-Ag-W-Cu	0.746
T-F-Ag-D-Cu	0.874	T-F-Ag-M-Cu	0.860

5.6.2 Nutritional value and calorie content of multilayer glazed fruit and vegetable chips

The nutritional value and calorie content of the multilayer chocolate glazed chips are presented in **Table 5.8**. The nutritional content of the developed compositions of chocolate-covered chips is as follows (g 100 g^{-1}): protein – 8.02–11.94; fat – 15.09–18.02; carbohydrates – 47.48–58.23. The effect of adding freeze-dried currant powder to the glaze of different types of chocolate on the protein, fat and carbohydrate content of multilayer glazed chips is statistically insignificant. This is due to the small amount of currant powder in the chocolate glaze.

Table 5.8 Nutritional value and calorie content of multilayer glazed chips [40]

Multilayer glazed chips	Protein, g 100 g^{-1}	Fat, g 100 g^{-1}	Carbohydrates, g 100 g^{-1}	Calorie content, kcal 100 g^{-1}
Z-F-Ag-W	10.40±0.37	17.92±0.42	54.32±1.17	406.0
Z-F-Ag-M	9.89±0.34	16.63±0.38	55.49±1.02	397.6
Z-F-Ag-D	10.03±0.29	17.41±0.51	53.67±1.10	398.3
Z-F-Ag-W-Cu	10.44±0.31	17.93±0.44	54.50±1.09	406.9
Z-F-Ag-M-Cu	9.92±0.24	16.72±0.36	55.92±0.98	398.0
Z-F-Ag-D-Cu	10.03±0.37	17.40±0.38	53.83±1.15	398.8
Z-F-C-W	11.91±0.36	18.02±0.40	48.22±1.07	390.1
Z-F-C-M	11.39±0.42	16.84±0.39	49.32±1.09	381.2
Z-F-C-D	11.52±0.40	17.63±0.39	47.48±1.16	382.0
Z-F-C-W-Cu	11.94±0.33	18.01±0.33	48.34±1.11	390.5
Z-F-C-M-Cu	11.41±0.28	16.82±0.34	49.40±1.14	381.7
Z-F-C-D-Cu	11.52±0.37	17.60±0.42	47.62±1.00	382.5
A-F-C-W	9.92±0.32	16.72±0.45	50.82±1.13	380.8
A-F-C-M	9.39±0.35	15.49±0.36	51.88±1.02	372.0
A-F-C-D	9.51±0.33	16.29±0.18	50.21±1.10	372.8
A-F-C-W-Cu	9.91±0.38	16.72±0.25	50.93±1.17	381.3
A-F-C-M-Cu	9.40±0.40	15.53±0.18	52.03±1.08	372.5
A-F-C-D-Cu	9.52±0.37	16.29±0.30	50.32±1.08	373.2
A-F-Ag-W	8.52±0.36	16.58±0.33	57.04±1.11	397.2
A-F-Ag-M	8.03±0.38	15.40±0.31	58.12±1.19	388.3
A-F-Ag-D	8.14±0.27	16.23±0.35	56.41±1.15	389.1
A-F-Ag-W-Cu	8.52±0.35	16.59±0.29	57.10±1.14	397.6
A-F-Ag-M-Cu	8.02±0.31	15.40±0.36	58.23±1.01	388.8
A-F-Ag-D-Cu	8.14±0.26	16.21±0.19	56.52±1.07	389.5
T-F-Ag-D	8.33±0.26	16.12±0.22	50.18±1.02	366.6
T-F-Ag-D-Cu	8.33±0.18	16.11±0.24	51.01±1.08	369.6
T-F-Ag-W-Cu	8.40±0.21	15.12±0.18	52.49±1.19	366.5
T-F-Ag-M-Cu	8.27±0.17	15.09±0.11	52.64±1.21	366.4

The protein content of multilayer chips covered with different types of chocolate varies as follows (g 100 g^{-1}):

– covered with white chocolate – 8.40–11.94;
– covered with milk chocolate – 8.02–11.41;
– covered with dark chocolate – 8.14–11.52.

Chips containing apple and table beet had lower protein content than those containing zucchini and carrots.

Multilayer chips glazed with milk chocolate had the lowest fat content (15.09–16.84 g 100 g^{-1}). The fat content of chips glazed with white and dark chocolate was 15.12–18.02 g 100 g^{-1} and 16.11–17.63 g 100 g^{-1}, respectively. Regardless of the type of chocolate used for the glaze, the fat content of the zucchini and carrot chips was higher.

Chips glazed with dark chocolate had the lowest carbohydrate content 47.48–56.52. The carbohydrate content of chips glazed with white and milk chocolate was 48.22–57.10 and 49.32–58.23, respectively. The highest carbohydrate content was found in multilayer chips in which the plant raw material of the base and the grated layer was apple.

The calorie content of chocolate-glazed chips ranged from 366.4 to 406.9 kcal 100 g^{-1}. Chips glazed with white chocolate had more calories than those glazed with milk and dark chocolate.

The mineral content of multilayer glazed chips is presented in **Table 5.9**, which shows the effect of the type of chocolate on the mineral content of the chips. The mineral content of the glazed chips varied as follows (mg 100 g^{-1}):

– iron (Fe) – 2.60–5.10;
– magnesium (Mg) – 92.07–145.88;
– calcium (Ca) – 71.22–212.25;
– potassium (K) – 457.8–1228.0.

Multilayer chips glazed with dark chocolate had a higher iron content than those glazed with white and milk chocolate. The iron content of the chips was also increased by adding currant powder to the chocolate glaze. The highest iron content (5.10 mg 100 g^{-1}) was found in the A-F-Ag-D-Cu composition. The highest magnesium levels were also found in compositions glazed with dark chocolate. Adding currant powder to the glaze increased the magnesium content of the chips. The Z-F-C-D-Cu composition had the highest magnesium content (145.88 mg 100 g^{-1}). Milk glazed multilayer chips with currant powder had the highest calcium and potassium levels. Multilayer chips glazed with dark chocolate had the lowest calcium content. The lowest potassium levels were found in chips with white chocolate glaze.

Table 5.9 Mineral content of multilayer glazed chips

Multilayer glazed chips	Mineral content, mg 100 g^{-1}			
	Fe	Mg	Ca	K
Z-F-Ag-W	3.20	106.83	151.50	1075.0
Z-F-Ag-M	3.58	123.63	197.40	1127.0
Z-F-Ag-D	4.81	143.13	105.30	1098.0
Z-F-Ag-W-Cu	3.39	109.57	151.99	1087.0
Z-F-Ag-M-Cu	3.74	125.25	194.83	1137.0
Z-F-Ag-D-Cu	4.89	143.45	108.87	1109.0
Z-F-C-W	2.77	109.25	166.35	1166.0
Z-F-C-M	3.15	126.05	212.25	1219.0
Z-F-C-D	4.38	145.55	120.15	1189.0
Z-F-C-W-Cu	2.96	112.00	166.84	1179.0
Z-F-C-M-Cu	3.31	127.68	209.68	1228.0
Z-F-C-D-Cu	4.46	145.88	123.72	1201.0
A-F-C-W	2.98	96.14	135.03	632.3
A-F-C-M	3.36	112.94	180.93	685.1
A-F-C-D	4.59	132.44	88.83	655.4
A-F-C-W-Cu	3.17	98.89	135.52	645.0
A-F-C-M-Cu	3.52	114.57	178.36	694.3
A-F-C-D-Cu	4.67	132.77	92.40	666.7
A-F-Ag-W	3.41	93.72	120.18	540.6
A-F-Ag-M	3.79	110.52	166.08	593.4
A-F-Ag-D	5.00	130.02	73.98	563.7
A-F-Ag-W-Cu	3.60	96.46	120.67	553.3
A-F-Ag-M-Cu	3.95	112.14	163.51	602.6
A-F-Ag-D-Cu	5.10	130.34	77.55	574.9
T-F-Ag-D	4.02	125.63	71.22	468.2
T-F-Ag-D-Cu	4.10	125.95	74.79	479.4
T-F-Ag-W-Cu	2.60	92.07	117.91	457.8
T-F-Ag-M-Cu	2.96	107.75	160.75	507.1

Conclusions

Fruits, vegetables, and berries are seasonal products that spoil quickly and lose nutrients without proper storage conditions. Long-term storage of fruits, vegetables and berries requires the creation of special conditions that maintain recommended air temperature and air humidity regimes. Storage is an energy-intensive process and requires large warehouses. Therefore, it is advisable to process fruits, vegetables and berries directly at the farms where they are grown. The processing of these plant raw materials, in particular the production of chips from them, will allow agricultural producers not to lose the harvested crop, to refuse significant costs for its storage and to obtain additional profits. However, the production of chips requires technological equipment and production buildings for its installation, as well as qualified personnel.

Dried fruit and vegetable chips are positioned in the market as a healthy food. They can be a healthy snack between main meals. Their consumption allows the human body to obtain the necessary nutrients, especially vitamins, macro- and microelements. Chips made of plant raw materials can have a positive effect on the metabolism in the human body, prevent excessive food consumption and provide a balanced diet.

The results of the study can be summarized as follows:

1. For the production of "healthy" chips it is important to choose an effective technology. For their production it is recommended to use hot air drying at the temperature of the drying agent up to 80 °C. At this drying temperature, the nutrients contained in fresh fruits and vegetables can be preserved without significant losses in the finished product. In addition, in order to reduce the loss of nutrients during the production of chips, as well as to preserve the taste, smell and colour of the plant raw materials in the finished product, it is advisable to blanch the plant raw materials for a short time.

2. The processing of fruits, vegetables and berries into freeze-dried powders is a promising technology. Freeze-dried plant powders, especially raspberry, currant and strawberry, can be used in various combinations as an ingredient in multilayer chips to fortify them with minerals, as well as to diversify flavors.

3. Flax seeds are another innovative ingredient for chips. It is a source of useful substances for the human body. The combination of flax seeds with vegetables and fruits in one product (chips) makes it possible to balance the nutritional content.

4. Glazing multilayer chips with different types of chocolate increases the calorie content of snacks. The dark chocolate glaze fortifies the multilayer chips with iron and magnesium, and the milk chocolate glaze fortifies the chips with calcium and potassium. These chips can be recommended for children because they contain fruits and vegetables. At the same time, it is important that children consume these snacks in the recommended amounts.

5. Using the developed technology, it is possible to produce an innovative product (multilayer chips or chocolate-glazed multilayer chips) with original taste properties and nutritional composition. The possibility of combining different types of plant raw materials (vegetables, fruits, berries, flax seeds, etc.) in one product allows producers to obtain a wide range of multilayer chips with taste properties that satisfy the preferences of different categories of consumers. The combination of plant raw materials also makes it possible to balance the nutritional content of the chips and obtain a functional product for specific target groups of consumers.

6. According to the results of sensory analysis of chips with different combinations of plant raw materials and determination of the quality index of chips, the following multilayer chips are recommended for production: A-S-F-Pu, A-R-F-C, A-R-F-Pu, T-R-F-Ag. The nutritional value and the calorie content of these chips are in the following range: protein – 5.78–9.11 g 100 g^{-1}; fat – 8.40–8.66 g 100 g^{-1}; carbohydrates – 39.03–53.55 g 100 g^{-1}; calorie content – 246.1–312.0 kcal 100 g^{-1}. The following multilayer chocolate-glazed chips are also recommended for production: T-F-Ag-D-Cu, A-F-Ag-D, A-F-Ag-D-Cu. The nutritional value and the calorie content of these chips are in the following range: protein – 8.14–8.33 g 100 g^{-1}; fat – 16.11–16.23 g 100 g^{-1}; carbohydrates – 51.01–56.52 g 100 g^{-1}; calorie content – 369.6–389.5 kcal 100 g^{-1}.

Further research to determine the physicochemical and sensory properties of multilayer chips with different combinations of plant raw materials such as fresh vegetables, fruits, berries, seeds, freeze-dried plant powders, etc. is relevant.

Conflict of interest

The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this paper.

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