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# STUDYING THE LOSS OF MASS BY CAULIFLOWER DEPENDING ON AGROBIOLOGICAL FACTORS, VARIETAL FEATURES, AND PACKAGE TECHNIQUE

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Проведені дослідження ставили за мету наукове обґрунтування впливу погодних умов вегетаційного періоду капусти цвітної, вмісту деяких компонентів хімічного складу, фізичних властивостей та способів пакування на втрати маси головок капусти під час зберігання. Установлено, що під час зберігання капусти цвітної відбуваються такі види втрат: втрати маси за рахунок зменшення сухих речовин, за рахунок часткового випаровування води, розвитку мікроорганізмів та фізіологічних розладів.

Погодні умови дослідних років характеризувалися мінливістю. Зароки дослідження сума середньодобових температур коливалася від 1743,4 до 2544,3 °C і перевищувала верхню межу оптимальної суми на 58,9–380,3 °C. Гідротермічний коефіцієнт Селянинова (ГТК) становив 0,58–1,10. Вегетаційний період характеризувався від середньо посушливого до достатньо забезпеченого вологою.

Умови вегетаційного періоду вплинули на втрату маси головок капусти цвітної пізньостиглої під час зберігання: у контролі більшими природні втрати були у 2015 р. – 12,8–16,9 %, меншими у 2016 р. – 11,7–13,8 % залежно від гібрида. Різниця між гібридами за роки досліджень була істотною. Природні втрати маси головок капусти цвітної під час зберігання без упаковки в середньому за 2015–2017 рр. становили у гібрида Каспер F1 13,7 %, у Сантамарія F1 12,7 %, у Скайвокер F1 15,5 %.

Інтенсивність зниження вологи за температури зберігання капусти  $1 \pm 0,5$  °C коливається від 0,27 до 9,3 % залежно від способу пакування. При фасуванні у стретч-плівку інтенсивність випаровування вологи у всіх гібридів була однаковою і становила 0,3 % за добу. Стретч-плівку перфорована незначно збільшувала випаровування вологи від 0,37 % у гібрида Каспер F1 до 0,43 у гібрида Скайвокер F1. При зберіганні головок капусти у відкритому вигляді співвідношення втрати вологи до втрати сухих речовин коливаються у межах від 11,2 у головках Сантамарія F1 до 13,2 у головка гібриду Каспер F1. При використанні ПП відповідно 0,23–0,23, а у СПП 0,35–0,43.

Встановлена кореляційна залежність втрат маси капусти цвітної під час зберігання від ГТК, середньодобової температури та відносної вологості повітря вегетаційного періоду та від вмісту сухих речовин, об'єму та пористості головки. Рівняння регресії дають можливість прогнозувати втрати маси капусти цвітної під час зберігання залежно від погодних умов вегетаційного періоду та від вмісту сухих речовин та фізичних показників головок

Ключові слова: капуста цвітна, втрата маси, погодні умови, випаровування води, види пакування

## 1. Introduction

Representatives of the Cabbage family are universal vegetable crops, which represent a cheap, affordable, and useful

product. The availability of specialized sorts, different terms of ripening and economic purposes make it possible to use fresh and sour cabbage throughout the whole year. The biochemical composition of cabbage depends on sort characteristics, condi-

tions of cultivation and agrotechnology. Its nutritional value is very high, so people call cabbage the “Queen of Vegetables.” The energy value of cabbage vegetables is low, but their usefulness is in the content of ash elements, carbohydrates, nitrogenous substances, vitamins, organic acids, and others [1].

Cauliflower ranks second after white cabbage among the cabbage vegetables by areas. The largest crop areas of cauliflower are in Italy, France, Germany, Great Britain, and the Netherlands. The share of cauliflower makes up 10 % of the area occupied by vegetable plants in Germany. Cauliflower comes to consumers seasonally, so it is necessary to store it for consumption during a year [2].

The main purpose of storage of vegetables is to preserve their quality and to bring high quality products with minimal weight loss and deterioration of quality to the consumer. There are normalized quantitative weight losses or natural losses during storage of fruit and vegetable products. The weight of products decreases due to consumption of dry substances by respiration and transpiration of moisture. Unrationed loss associates with loss of quality. In addition, there are over-rationed losses, which include reduction of weight of products above the established norms, reducing of quality due to violation of transportation conditions and storage [3].

The maximum acceptable water loss makes up 7–8 % for white cabbage, potatoes, green pepper and tomatoes; 3–4 % for lettuce; 5–6 % for strawberries, raspberries, currants, peas and beans; carrots, beets. Vegetables and fruits lose their attractive product appearance after this maximum. Practice shows that it can reach 10–12 % or more. It depends on features of a sort, weather conditions of a vegetation season, methods of collection and storage [4].

The main part of natural losses (70–90 %) falls on water evaporation, therefore there is a decrease in water content and a relative increase in dry matter during storage of fruit and vegetable production [5]. It is necessary to create a high relative humidity of air in storage for cabbage, which is not always possible. Practice shows that fluctuations of temperature at high humidity in the storage can lead to condensation on surface of products. Therefore, water evaporation during cabbage storage is unavoidable.

The choice of methods and modes of storage, taking into consideration sort biological features and results of the forecast on intensity of natural weight losses, is one of the elements for improvement of the system of vegetable storage. Studies on cauliflower did not received proper development in this area.

Therefore, complex studies on objective indicators, which have the greatest impact on intensity of natural losses of weight of cauliflower, are expedient.

Prolonged storage of fruit and vegetable products leads to loss of quality and quantity. The problem of preservation of vegetables is quite expedient, since losses can reach 30 % or more during the receipt of products from a manufacturer to a consumer. It is possible to reduce losses significantly if to observe all technological processes of storage and transportation of products. Early forecasting of weight losses provides an opportunity to determine the theoretical storage capacity of vegetables before the start of storage. Based on the foregoing, the study on the weight loss of cauliflower during storage is expedient.

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## 2. Literature review and problem statement

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Vital activity, which is inherent in living objects, continues in vegetables after their separation from a mother plant.

These processes pass without an input of the environment of nutrients and water unlike the processes in the growing season. At the same time, the normal course of vital activity is possible at a certain energy level only and the support of such level requires maintenance by spare nutrients. Support of processes of vital activity at the required level is the main condition for storage of vegetables. It is necessary to create conditions that would slow down processes inherent in normal functioning of a living organism [6] during storage, but such conditions must not stop these processes completely.

These processes carry out the main biological objective by function purpose. It is preservation of vital functions of meristematic tissues for vegetative or generative reproduction. The determining process for vital activity is respiration and water evaporation. Other transformations maintain the indicated processes at the required level or provide natural resistance against adverse external influences. Implementation of vital processes requires energy generated by oxidation of organic substances. The content of these substances decreases, which leads to weight loss and deterioration of the quality of raw materials [5]. Existing conclusions are made for some types of vegetables. The connection between weight loss of cauliflower and content of dry matter in heads is currently unclear.

A chemical composition of fruits and vegetables affects the amount of water loss, which depends on the quantitative and qualitative state of water, as well as on the water-retaining ability of tissues. The intensity of water evaporation depends most of all on the total water content. The content of water in cauliflower ranges from 88 to 92 %. The water content in the bound state is 40–42 % of the total water content.

The biological meaning of the process of water evaporation is removal of heat released during respiration, prevention of a temperature rise in tissues and provision of movement of substances in a soluble state in different parts of fruits and vegetables. At the same time, there is a relaxation of cells turgor and the withering of tissues, which affects the normal course of metabolic processes adversely, causes a significant increase in intensity of respiration and decomposition of all substances and violates the energy balance. All mentioned leads to changes in functions of enzymes and their state. Thus, the resistance of vegetables to damages caused by microorganisms decreases. Water loss worsens the taste of a product. The product loses its juiciness, freshness and becomes withering. There are irreversible changes in the system of colloids of the protoplasm in vegetables, which leads to significant deviations in the normal process of metabolism [7].

On average, loss of two-thirds of weight occurs due to water evaporation and loss of one-third – due to spending of organic substances for vitality processes. This ratio is for the storage temperature of products below 5 °C. If the temperature exceeds 5 °C, losses increase considerably [8]. The large surface of the product body, lack of wax film and insignificant thickness of the cutis layer of cells contribute to significant loss of water through evaporation [9]. Transpiration, that is, the process of moisture loss through fruit surface, is the next cause of natural loss of weight. The coefficient of transpiration of vegetable crops is rather high. It is 539–743 for cabbage, 628–773 for beans, 600–843 for pumpkin. We should note that the coefficient of transpiration depends on the growing zone, weather conditions and plant age [10].

Climatic factors affect identification of varietal properties of vegetables significantly. It is necessary to grow their

sorts in climatic zones, which provide large and high-quality harvest products, have good storage and portability. The quality and storage of fruits in different areas is not uniform. Weather conditions have a significant effect on the process of ripening of vegetables. Low temperatures and excess of water in the soil lengthen the period of vegetation and delay the ripening. There were studies on dynamics of weight change of green parsley during storage conducted. The studies established a direct relationship between the level of weight loss, the amount of precipitation and the hydrothermal coefficient of the vegetation period ( $r=0.82...0.99$ ). The natural loss of weight correlated inversely with the sum of active temperatures ( $r=-0.76...-0.91$ ) [11].

Authors of paper [12] established that the level of daily natural loss of weight strongly correlated with weather factors during storage of plums.

Instead, the results presented are unmatched. Sort features, chemical composition, degree of hydrophilicity of cellular colloids, anatomical structure, and a state of surface tissues and a period of storage influenced loss of water due to evaporation during storage essentially [13]. Unfortunately, such studies on cauliflower are very scarce.

Evaporation of water depends on the storage period. Thus, evaporation of water goes actively at the beginning of storage of white cabbage – up to 800 g per 1 ton of heads, it decreases to 600 g in the middle of the period of storage and it rises again to 700 g at the end, with the approach of a new vegetation season. The intensity and amount of evaporated water depends on its content in heads, and on the temperature and the relative humidity of the air. The higher the temperature is and the lower relative humidity of the air is in a storage of cabbage heads, the more they evaporate water and vice versa [5]. Instead, the studies did not consider a rate of reduction of weight loss in cabbage heads during the period of storage.

Reducing of water penetration through surface tissues of a product is possible by the use of packaging materials in the form of polyethylene packaging (PEP).

Sweet peppers packaged in a film at a temperature of 1 °C and stored for up to 30 did not show degradation of quality. Output of products was 100 % [14]. The use of a polyethylene film made it possible to keep broccoli heads for 6 days at 5 °C without significant loss in weight, color, C and E vitamins, and antioxidants [15].

Packaging in a shrinkable film or individual sealed packaging in a high-density polyethylene film is another effective way to extend the shelf life of cucumbers. The polyethylene coating may extend the shelf life of a cucumber from 2 days to 5 days (the increase in 2.5 times) at 23 °C and from 10 days to more than 13 days at 12 °C [16].

It was possible to store squashes, which have high intensity of respiration at the room temperature (155.7 mg CO<sub>2</sub>/kg/h), for 25 days at 5±2 °C. In a package with a minimum weight loss of 0.06 % and a slight change in the amount of vitamin C, the total amount of soluble dry matter, carotenoids, and water evaporation. Microbial loads of mesophilic aerobic and coliforms were below the threshold level. There was no growth of yeast and mold at the end of the storage period [17].

Storage of beet roots in boxes with polyethylene film provided a high yield (85–91 %) of marketable roots [18].

We can divide factors that affect weight loss of vegetables into biological factors and technological factors. The biological factors that affect an amount of natural losses include anatomical structure and chemical composition of

vegetables, their physical condition and presence of mechanical damage by pests and diseases. The cause of these factors is primarily the features of types and sorts of vegetables, conditions of cultivation, harvesting and natural resistance to adverse external conditions. An important factor is the ratio of free and bound water in fruit tissues, intensity of respiration, permeability of cytoplasmic membranes and surface tissues in relation to water. Intensity of evaporation is greater, the greater is the specific surface area of the storage object under the same external conditions. Therefore, water evaporates more from small vegetables of the same variety under the same conditions than from large ones [19–21].

A rate of loss decrease in vegetable storage is uneven. Processes of vital activity slow down during transition to rest state, and respiration decreases especially. Intensity of respiration increases during preparation for germination and in the process of germination of vegetable growth points (seeds, buds, corns). There is a sharp decrease of all life processes after. The level of respiration in the last period of storage increases due to formation of meristematic tissues with cells, which have a greater number of mitochondria. Biosynthesis of substances and formation of new tissues requires energy. That is why there is an increase in intensity of respiration at the end of storage and, as a consequence, an increase in water evaporation [22].

Thus, weight loss was at the level of 2.2–2.5 % during the first day of storage of strawberries. Losses increased by 0.2–0.4 % during the next 24 hours of storage, and made up 2.3–3.3 % at the end of the period of storage [23].

There are no studies on a rate of weight loss of cauliflower in different stages of storage.

Heads of cauliflower are shortened, thick and juicy flowering sprouts. Formation of a dense head is similar to formation of white cabbage. Head sprouts appear consecutively from axils of underdeveloped leaves. Large and denser heads have more branched sprouts. The maximum heads suitable for a farm have the diameter of 11–12 cm. Such a head has the most branched sprouts in the lower part, branching decreases in the direction to the top, and the main weight of a head at the very upper part is the cones of growth of first-order sprouts. Large and denser heads have more branched sprouts. The total number of branches in large heads can reach two thousand. There is germination of flower organs in the cones of the growth of sprouts of a head in the phase of technical ripeness [24]. Along with this, sprouts are an active area for water evaporation.

Head sprouts serve as a reservoir of nutrients necessary to maintain vital functions of growth points – buds. The buds are in a state of rest in the period of storage. There is no deep rest in cauliflower. There goes nutrients consumption during storage and cauliflower loses its resistance to phytopathogenic microorganisms gradually. For this reason, there is actually no damage caused by gray rot and other diseases during the first period of storage of cauliflower.

The structure of vegetables is a distinctive feature of their type and sort. Vegetables with thin surface tissues have more lenticels and more moisture evaporates from them. Such vegetables include cabbage vegetables, leafy greens, fruit vegetables, and root crops. Not only a type and sort of vegetables determine the state of surface tissues, but also conditions of cultivation and a degree of ripeness. Weather conditions of the period of fruit formation strongly influence intensity of weight loss of vegetables and fruits during storage [25]. Vegetables grown in cold and rainy summer are less formed, their

surface tissues are thin and contain less cutin, wax or suberin. The period of ripening comes later for such fruits, surface tissues are not formed sufficiently. This leads to a significant increase in losses due to water evaporation. There is irrigation of vegetable tissues at considerable watering [26, 27]. Intensity of transpiration determines the ratio of a surface of a fruit to its volume or of a surface to weight, surface structure of a fruit, including a number and a size of stomata and lenticels, thickness and composition of a cuticle [28]. A rate of the transpiration process and the amount of water loss depends on a surface area of fruit, and not on their weight [29]. Thus, a rate of water loss in aubergine of the largest size is 2 times higher than in the smallest ones, and higher values of the ratio of a surface area of fruit to their weight in small fruits partly explain the higher level of their transpiration [28].

The conducted studies on the amount of natural weight loss of strawberry during storage showed a significant dependence of the amount of losses on the diameter of berries (the degree of influence of the factor made up 20.2 %, and its interaction with the storage duration was 43.3 %) [30].

Technological factors determine the amount of natural weight losses. They include storage modes. The amount of water losses depends on the relative humidity of the air and temperature, which determine lack of water vapor in the environment, and intensity of respiration – on temperature and gas composition. Lack of moisture in the air and on the surface of a product determines a rate of removal of evaporated water. The removal of water vapor from the surface of a product stimulates water evaporation through surface tissues. This process can occur not only due to lack of moisture, but also due to increased moisture exchange [4].

The greatest specific weight of unnormalized losses (80–90 %) belongs to microbiological and physiological diseases. An important physiological factor, which influences development of microbiological and physiological diseases, is natural resistance of vegetables to microorganisms – pathogens of diseases and adverse external conditions, which cause physiological disorders. Other biological factors, such as sort features, conditions of cultivation and physiological state of vegetables, can only strengthen or weaken natural resistance and participate in its creation and support [6].

Thus, the loss of weight of fruit and vegetable products is a function with many arguments. The above shows that determination of a type of weight loss of cauliflower heads during storage, depending on the conditions of the vegetation season, varietal peculiarities, a type of packaging, is scarce, they are unmatched and generalized.

If we know and control factors, which affect weight loss of cauliflower during storage, we can reduce them significantly and extend duration of storage.

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### 3. The aim and objectives of the study

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The objective of the study was to examine weight loss of cauliflower during storage, depending on conditions of the vegetation season, sort features and the method of packaging.

It was necessary to solve the following tasks to achieve the objective:

- analysis of weather conditions of the vegetation season of cauliflower;
- study on the influence of weather conditions of the vegetation season of cauliflower on the weight loss during storage;

- determination of intensity of water evaporation from heads of cauliflower flowers depending on a type of packaging;
- establishment of the relationship between intensity of the weight loss of cauliflower heads and weather conditions of the vegetative season of cauliflower plants, content of dry matter and some physical indicators.

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### 4. Materials and methods to study the weight loss of cauliflower during storage

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We performed field experiments in accordance with generally accepted methods. We carried out the study on the following late-ripening cauliflower hybrids: Skywalker F<sub>1</sub>, Santamaria F<sub>1</sub> and Casper F<sub>1</sub> (control version is Casper F<sub>1</sub>). The term of planting of seedlings was the first ten days of June. The method of growing was seedlings (we planted seedlings with four or five true leaves). The method of placement of plants was a tape with a scheme of placement (40+100)×50 cm. The density of plants was 28.6 thousand pieces/ha. The repeatability in studies was four times. It was two-factor study: we studied the influence of A factor – characteristics of the hybrid, and factor B – conditions of the vegetation season. The area of each sown area was 21 m<sup>2</sup>. Placement of variants was systematic.

We took standard products for storage. We cooled heads of cauliflower to a storage temperature before storage. We stored cauliflower in the Polair Standard KXH-8.81 refrigerating chamber at a temperature of 0±1 °C and relative humidity of 90–95 % in polymer boxes [31].

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### 5. Results of studying the weight loss of cauliflower heads during storage

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#### 5.1. General characteristics of weather conditions of the vegetation season during formation of cauliflower heads

Deepening and expansion of studies on formation of quality of cold-resistant vegetable plants is relevant under existing conditions of climate warming. Therefore, it is necessary to determine the extent of affection of the climatic conditions of the vegetative season on the growth and development of cabbage plants.

It is necessary to determine a length of the vegetation season and a number of days with a temperature higher than the minimum for individual stages of development for each plant.

We used the sum of average daily temperatures calculated by addition of average daily temperatures for a known period for approximate determination of possibility of growing of plants in different climatic areas. We also considered the sum of the temperatures as the constant temperature, or the temperature factor. The average daily temperature ranged from 1,743.4 (in 2017) to 2,544.3 °C (in 2015) during the years of studies. It exceeded the upper limit of the optimal amount by 58.9–380.3 °C.

The negative effect of moisture manifests itself in the absence of light often, as well as in windy weather. Watery tissues of plants are much more susceptible to bacterial rot and diseases of mushroom origin. Lack of moisture also leads to harmful changes in tissues. Excess of moisture stimulates development of wet rot, and dryness stimulates dry rot. The amount of precipitation ranged from 93.1 mm in 2015 to 240.9 mm in 2016 during the vegetation season. Sharp transitions from humidity to dryness, from high



temperatures to low ones affect formation of the harvest quality negatively especially if such phenomena occur repeatedly. At the same time there is hardening and stiffening of tissues of plants and retardation of heads growth. 2016 was the most favorable for growth and development of cabbage plants.

It is necessary to pay attention to distribution of precipitation during a year. In the first place, the vegetative season should occur under conditions of sufficient and uniform soil moisture. An indicator of suitability of a particular area for the cultivation of individual crops is the average annual temperature ( $t$ ) and the sum of annual precipitation ( $S$ ). The following formula determines the boundary of arid areas:  $S=3(7.2+7)$  cm. Climatic zones with precipitation over  $S=3(t+7)$  cm (by Gregor) are suitable for growing of field crops. We performed calculations for Kharkiv region  $t=7.2$ ;  $S=529$  mm. Thus,  $S=3(7.2+7)=50.4$  cm (504 mm), that is, precipitation is more than the minimum required for plant cultivation by 25 mm. The so-called rain factor ( $df=S/t$ ) shows the amount of average annual precipitation, which fall on 1° of average annual temperature and characterize this area. Areas with  $df$  from 10 to 40 are arid, from 40 to 70 – are transient, from 70 to 100 – are wet, more than 100 – very wet.  $df=504:7.2=70$  for Kharkiv region. That is, this area is transitional.

The dryer is a region ( $s=10$  s), the lower is actual humidity index ( $S-s$ ): $t$ . Areas with ( $S-s$ ): $t$  value from 4 to 0 are the most dry; from 1 to 7 – are very dry; from 8 to 14 – are medium or moderately arid; from 15 to 21 – are transitional; from 22 to 28 – are moderately wet; from 29 to 35 – are averagely wet, more than 36 – are strongly wet. S annual amount of precipitation in Kharkiv is 529 mm, and  $t=7.2$  °C. Thus,  $s=10-3(7.2+7)=504$  mm. We determine the average actual humidity from formula:  $(529-504):7.2=3.5$ .

Moderate rain precipitations, in particular those that fall in critical periods, when the quality and quantity of crop depends on them are favorable for cultivation of fruit and vegetable crops with high quality and long storage life.

We used the integrated index of temperature and precipitation – hydrothermal coefficient (HTC) for objective estimation of meteorological conditions of the vegetation season of cauliflower. We performed a comparative estimation of years of study according to HTC. It was 0.58 in 2015, and we can consider this period as medium-dry according to the classification by G. T. Selyaninov. The vegetation period was sufficiently wet (HTC=1.10) in 2016. This indicator was 0.46 in 2017, so we consider this period as very dry. The period of mass ripening of heads of late-ripening cauliflower hybrids fell on the first 10 days of September in 2015 (there were no precipitation observed, the average daily temperature was 23.2 °C, the air humidity was 52 %, which was lower than the average air humidity for previous years by 15 %), while in 2016 this period fell on the first decade of October (the precipitation amount was 13.6 mm, the average daily temperature was 17.9 °C, air humidity was 76 %). In 2017, we collected cauliflower in the third decade of September, when the meteorological conditions were favorable for formation of the crop: the amount of precipitation was twice higher than the average annual temperature, the air temperature was 14.8 °C, and the air humidity was 71 %.

Thus, we can compare actual weather conditions of vegetation seasons with optimal vegetation seasons and conclude that 2015–2017 were dry, but more favorable years for formation of cauliflower – 2016.

### 5. 2. Types of weight loss of cauliflower heads during storage, depending on weather conditions of the vegetation season and methods of packaging

The vitality processes are intense after separation of product body from a mother plant. Large loss of dry matter and water evaporation accompanies these processes.

Mass losses and the overall preservation of cauliflower depend on exogenous and endogenous factors. Plants are complex dynamic self-organizing systems that use various principles of self-regulation in the process of life. Thus, if we compare cauliflower varieties subjected to identical exogenous factors, the decisive influence on changes of physiological, biochemical and physical properties will have endogenous factors, which are reflections of internal inherited properties of an organism. Therefore, weight loss is lower in varieties with longer storage life. The conditions of the vegetation season affected weight loss of late-ripening cauliflower heads during storage as follows: the greater natural losses were in 2015 – 12.8–16.9 % (HTC=0.58) in the control, the lowest weight loss was in 2016 – 11.7–13.8 % (HTC=1.10) depending on the hybrid. The difference between hybrids in the years of studies was significant.

We performed a pair correlation analysis to identify factors of significant influence on the amount of weight loss of cauliflower (Table 1).

For the hybrids of cauliflower under study, the closest bonding of the inverse direction exist between weight loss, and HTC ( $r=-0.53882$ ) and the average daily temperature of the vegetation season ( $r=-0.53378$ ). The relative humidity of the air has a weak correlation with weight loss of cauliflower heads ( $r=0.283237$ ).

Table 1

Coefficients of correlation of pair bonding for cauliflower

	y	$x_1$	$x_2$	$x_3$
y	1			
$x_1$	-0.53882	1		
$x_2$	-0.53378	0.437387	1	
$x_3$	0.283237	0.187809	-0.77635	1

Note:  $X_1$  – HTC,  $X_2$  – average daily temperature, °C;  $X_3$  – relative humidity of the air, % during vegetation season

We performed a regression analysis to detect the combined effect of the studied factors on weight loss of cauliflower. We used the Regression tool of Data Analysis in MS Excel to construct a linear multiple regression model.

$$Y=-4.24-2.25 x_1+0.22 x_2+0.11 x_3,$$

where  $x_1$  is HTC,  $x_2$  is the average daily temperature of the vegetation season, °C;  $x_{3m}$  is the relative humidity of air during vegetation season, %.

The main indicators of multiple regression with selected factors are as follows: the coefficient of multiple correlation  $R=0.6977$ , the determination coefficient  $R^2=0.4867$ , it indicates that the variation of the factors presented in the equation explains 48.7 % of the variation of the result. The adjusted determination coefficient  $R^2=-0.778$  defines the relationship, taking into consideration the degree of freedom of the general and the residual dispersions. Standard error of estimation  $S=1.20$  estimates the accuracy of the study 100–1.2=98.8 %. The value of Fisher's criterion  $F_f=2.84$  by  $F_t=3.18$ . Since  $F_f>F_t$ , then we conclude that the regression equation is significant with probability  $1-\alpha=0.95$ .

On average, over 2015–2017, the natural weight loss of cauliflower heads (Fig. 1) during storage without packaging made up 13.7 % in Casper F<sub>1</sub> hybrid, 12.7 % in Santamaria F<sub>1</sub>, and 15.5 % in Skywalker F<sub>1</sub>.

sible to remove excess moisture by ventilation in a timely manner, therefore, favorable conditions for development of microorganisms and physiological disorders appear during prolonged storage [32].

We did not observe diseases and physiological disorders in heads of cauliflower kept in control during storage. Anthracnose, gray rot and vascular bacteriosis affected products when we packaged them. The first signs of disease and physiological disorders appeared on 30–40th day of storage in packaged variants. The products stored in boxes with polyethylene tabs were more affected. On the 70th day, losses reached 9.5–10.0 % depending on the hybrid. Development of pathogenic microorganisms began only from 70–80th days of storage and it was slower when we packaged heads of late-ripening cauliflower in stretch film. We observed losses of products more than 10.0 % on 110th day of storage on average over the years of studies (Fig. 2).

The dispersion analysis showed that the share of the influence of the type of packaging on the total natural weight loss of late-ripening cauliflower heads during storage was 23 %, the characteristics of the hybrid – 22 %, storage duration – 13 % (Fig. 3). The packaging of heads of late-ripening cauliflower hybrids affected their losses due to diseases and physiological disorders. Packaging of heads individually in a stretch polyethylene film reduced losses on average – 6.0–6.3 % depending on the hybrid over the years of studies. The dispersion analysis found that the type of packaging affected loss of products due to diseases and physiological disorders by 24 % during storage, hybrid features – by 33 %, storage duration – by 25 % (Fig. 4)

The type of packing had almost the same effect on weight loss of cauliflower and loss due to microbiological and physiological damage (23–24 %). The peculiarity of the hybrid was 22–33 %, respectively. We can explain the greater impact on weight loss due to microbiological and physiological damage by different natural immunity of varieties and hybrids. Other factors, such as weather conditions of the vegetation season and growing conditions, have a greater effect on weight loss of cauliflower (42 %) than on development of microorganisms. Microbiological processes, which occur during storage of vegetables, can be the result of development of hidden signs of microorganism damage that occurs during the period of cultivation or infection after harvesting, during transportation, market processing and storage. The sources of infection are phytopathogenic microorganisms, which are common in the soil, plants and equipment.

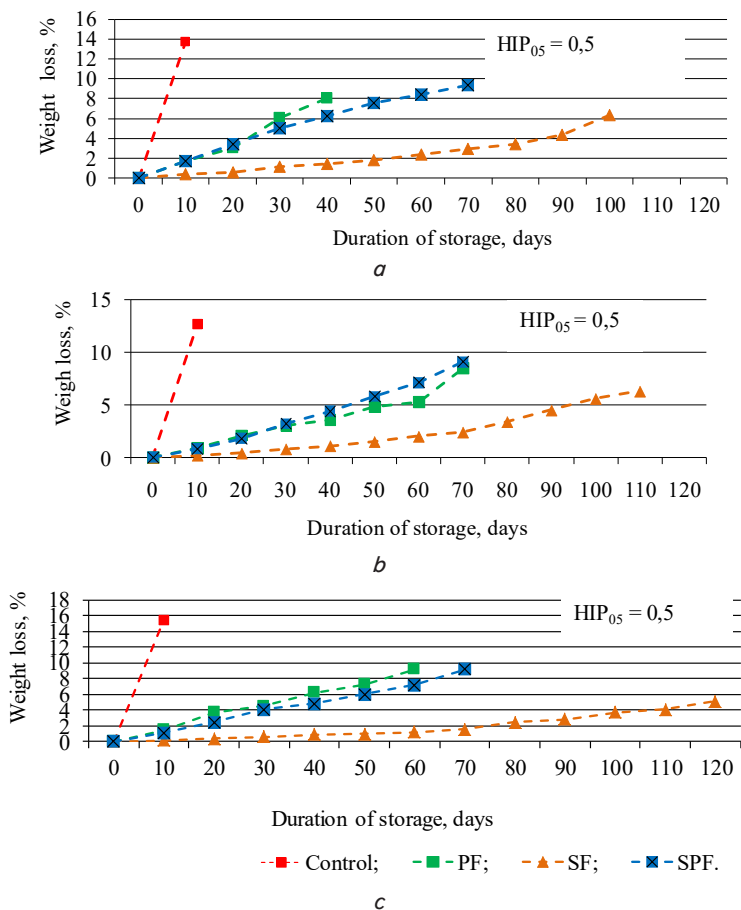


Fig. 1. Dynamics of the natural weight loss of cauliflower heads depending on the features of the hybrid and the type of packaging (2015–2017): a – Casper F<sub>1</sub>, b – Santamaria F<sub>1</sub>, c – Skywalker F<sub>1</sub>

The use of polyethylene film increased duration of storage of heads of Santamaria F<sub>1</sub> and Skywalker F<sub>1</sub> hybrids up to 70 and 60 days, respectively. At the same time, the natural mass losses decreased on average over the years of studies in comparison with the control in 1.7 and 1.5 times respectively and they were 9.2 and 8.5 %, respectively. Duration of storage extended to 40 days in heads of Casper F<sub>1</sub> hybrid, natural losses decreased in 1.7 times, they made up 8.0 %.

Stretch film packaging increased storage duration of Casper F<sub>1</sub> and Santamaria F<sub>1</sub> hybrid heads up to 100 and 120 days, while natural weight loss, as compared to control, decreased in 2.2 and 2.0 times, respectively, and it made up 6.3 %. Duration of storage of heads of Skywalker F<sub>1</sub> hybrid extended to 130 days, natural weight loss was 6.0 %, which was 2.9 times less than the control version. The use of perforated stretch lengthened the storage life of late-ripening cauliflower up to 70 days on average over the years of studies. The natural weight loss was less in 1.4–1.7 times compared to the control depending on the hybrid at the end of storage.

The use of film creates MGE around a head, this maintains marketable appearance and extends duration of its storage by reducing of intensity of respiration and moisture evaporation. However, packaging makes impos-

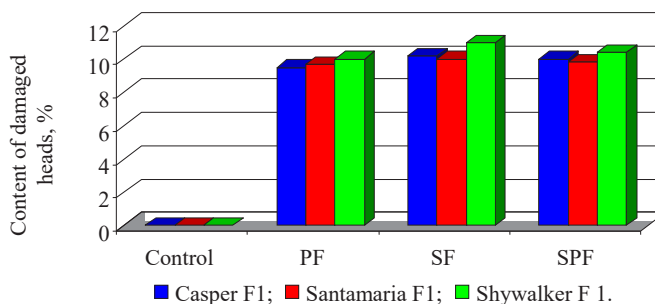


Fig. 2. Loss of cabbage heads due to microbiological and physiological disorders

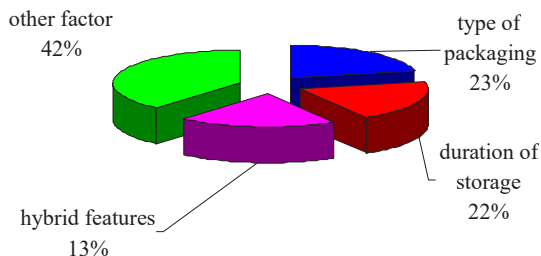


Fig. 3. Share of influence of the investigated factors on weight loss of cauliflower

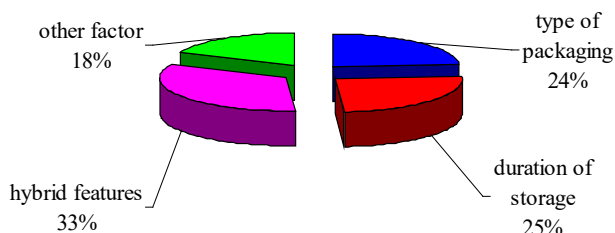


Fig. 4. Share of influence of the investigated factors on weight loss of cauliflower due to microbiological and physiological damage

Packaging of cauliflower decreased the intensity of water evaporation. We analyzed the structure of weight losses (Table 2). The intensity of moisture reduction at the storage temperature of cauliflower of  $1\pm 0.5\text{ }^{\circ}\text{C}$  varies from 0.27 to 9.3 % depending on the method of packaging (Fig. 5).

product itself. It helps to reduce intensity of respiration of products, release of moisture during respiration and loss of spare substances. The evaporation of moisture, in addition to the type of packaging, depends on characteristics of the hybrid.

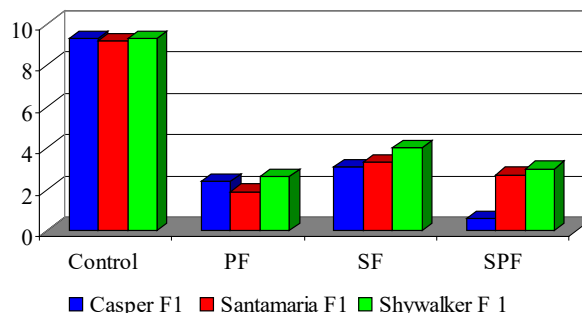


Fig. 5. Intensity of moisture reduction, depending on the type of packaging, %/days

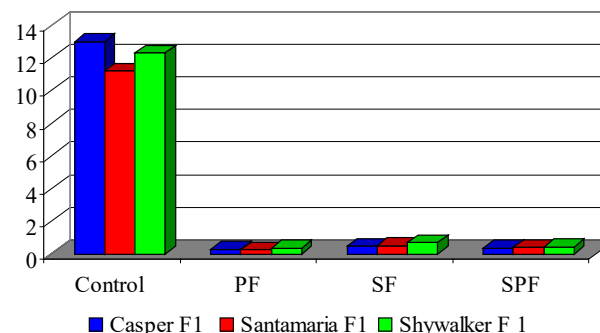


Fig. 6. Ratio of moisture loss to the loss of dry matter

Table 2

Structure of natural weight loss of cauliflower heads during storage, depending on the type of packaging and hybrid

Type of packaging	Hybrid	Duration of storage, days	Natural weight loss, %	Natural weight loss, %	
				due to loss of dry matter	due to moisture evaporation
Control	Casper F <sub>1</sub>	10	13.7	07.1	92,9
PF		40	8.0	76.4	23,6
SF		100	6.3	68.9	31,1
SPF		70	9.4	73.8	26,2
Control	Santamaria F <sub>1</sub>	10	12.7	08.2	91,8
PF		70	8.5	81.0	19,0
SF		110	6.3	66.8	33,2
SPF		70	9.1	72.7	27,3
Control	Skywalker F <sub>1</sub>	10	15.5	07.5	92,5
PF		60	9.2	73.9	26,1
SF		130	6.0	59.4	40,6
SPF		70	9.2	69.5	30,5
HIP <sub>05</sub>			0,5		

The intensity of evaporation of moisture in all hybrids was the same at packaging in the stretch film and it made up 0.3 % per day. The perforated stretch film slightly increased evaporation of moisture from 0.37 % in Casper F<sub>1</sub> hybrid to 0.43 in Skywalker F<sub>1</sub> hybrid.

The ratio of moisture loss to loss of dry matter ranged from 11.2 in Santamaria F<sub>1</sub> heads to 13.2 in Casper F<sub>1</sub> heads at keeping cauliflower unpackaged. When using PP, respectively, it was 0.23–0.23, respectively, at the use of PF and 0.35–0.43 at the use of SPF (Fig. 6).

The oxygen content decreases and the carbon dioxide content increases in sealed packaging, due to respiration of a

### 6. Discussion of results of studying the type of weight loss of cauliflower heads during storage

Volume, specific weight, and porosity of heads influence weight loss during storage. The cauliflower hybrids differed from each other by these characteristics. A volume of a head of the late-ripening cauliflower hybrids ranged from 331.5 to 616.5 cm<sup>3</sup> depending on characteristics of the hybrid and it was significantly ( $HIP_{05}=25.5$ ) less in Santamaria F<sub>1</sub> over the years of studies. On average, in 2015–2017, Skywalker F<sub>1</sub> had a larger head volume – 464.0 cm<sup>3</sup>, which exceeded Casper F<sub>1</sub> by 5.2 % by this characteristic. The specific weight of cauliflower heads varied from 1.01 to 1.05 g/cm<sup>3</sup> depending on the hybrid, but it did not differ significantly, during 2015–2017. Casper F<sub>1</sub> and Santamaria F<sub>1</sub> hybrids had on average the larger specific weight of heads (1.03 g/cm<sup>3</sup>) over the years of studies.

Physical density depends on the anatomical structure of both a head in general and juicy tissues in particular: thickness of skin or surface tissues, density of adherence of cells to one another, degree of ripeness, etc. [33].

We observed greater physical density of cauliflower heads in 2016 – 1,033.7–1,055.7 kg/m<sup>3</sup>, depending on characteristics of the hybrid. Heads with the physical density of 1,009.1–1,052.3 kg/m<sup>3</sup> formed in dry 2015 and 2017. It was less than in 2016 by 2.4 %. In 2015, the sharp onset of hot and dry conditions during the time of formation of the crop led to formation of cauliflower heads with the lowest physical density over the years of studies, it was 1,009.1–1,012.8 kg/m<sup>3</sup>. On average, in 2015–2017, it ranged from 1,023.9–1,040.3 kg/m<sup>3</sup> depending on features of the hybrid it was substantially greater ( $HIP_{05}=9.1$ ) in Santamaria F<sub>1</sub>.

Porosity is an indicator that determines presence pores filled with air in juicy products. It depends on the anatomical structure of vegetables or fruits, features of a sort or hybrid, weather conditions and growing technology. Weather conditions were favorable for formation of cauliflower heads in 2016, therefore the products had a high physical density due to good saturation of cells with water, which caused almost complete absence of pores in heads. Weather conditions were dry and hot during formation of cauliflower heads in 2015 and 2017, which increased their porosity. The porosity of heads varied within the range of 0.3–2.5 % depending on the hybrid in 2016, and in the range of 0.7–2.9 % in 2017. The porosity of heads was greater – 2.0–3.3 %, due to sudden drought at the time of their technical ripening in 2015. The hybrids differed considerably from each other in porosity of heads during the years of studies. On average, in 2015–2017, the porosity of cauliflower heads was in the range of 1.1–2.9 %. Skywalker F<sub>1</sub> had greater porosity of a head – 2.9 %, and Casper F<sub>1</sub> had a lower one – 1.1 %.

We performed a pair correlation analysis to identify the factors of significant influence on the amount of weight loss of cauliflower (Table 3).

Coefficients of correlation of pair ties for cabbage color

	<i>y</i>	<i>x</i> <sub>1</sub>	<i>x</i> <sub>2</sub>	<i>x</i> <sub>3</sub>	<i>x</i> <sub>4</sub>	<i>x</i> <sub>5</sub>	<i>x</i> <sub>6</sub>
<i>y</i>	1						
<i>x</i> <sub>1</sub>	0.139439	1					
<i>x</i> <sub>2</sub>	0.511261	0.815778	1				
<i>x</i> <sub>3</sub>	0.75915	-0.20468	0.368028	1			
<i>x</i> <sub>4</sub>	-0.85824	-0.10306	-0.53556	-0.89809	1		
<i>x</i> <sub>5</sub>	0.754077	0.374101	0.548853	0.577282	-0.87672	1	
<i>x</i> <sub>6</sub>	-0.38547	-0.02948	-0.5466	-0.69498	0.44697	-0.04135	1

Note: *x*<sub>1</sub> – dry matter content, %; *x*<sub>2</sub> – volume of cauliflower head, cm<sup>3</sup>; *x*<sub>3</sub> – physical density, kg/m<sup>3</sup>; *x*<sub>4</sub> – porosity, %; *x*<sub>5</sub> – specific weight, kg/m<sup>3</sup>; *x*<sub>6</sub> – true density, kg/m<sup>3</sup>

According to the results of a pair correlation analysis, we can state that the porosity (*r* = -0.85824), physical density, kg/m<sup>3</sup> and specific weight, kg/m<sup>3</sup> strongly affect the weight loss of cauliflower heads. Volume of a cauliflower head has an average connection with the weight loss. According to Becker [29], the amount of weight loss depends on a surface area of fruit, and not on their volume, which confirms our statements.

Changes in the chemical composition accompany anatomical-morphological processes. They are closely related to the direction and intensity of microbiological processes.

The weight loss of cauliflower depends on the content of components of the chemical composition. Skywalker F<sub>1</sub> and Casper F<sub>1</sub> had higher content of dry matter among the late-ripening hybrids on average during the years of studies. It was 12.2 and 14.7 %, respectively. The accumulation of dry soluble substances made up 6.6–7.5 % depending on the hybrid, the highest content was in Santamaria F<sub>1</sub> – 7.5 %. Skywalker F<sub>1</sub> had the highest overall sugar content – 3.4 %. The highest content of ascorbic acid was also in Skywalker F<sub>1</sub> hybrid, it was 89.4 mg/100 g. The content of dry matter in the late-ripening hybrids studied had a strong direct correlation with the sum of active temperatures (*r* = 0.83...0.99) and the air humidity during formation of a head (*r* = 0.92...0.99).

Based on the foregoing, the weight loss during cauliflower storage is a function, which depends on the chemical composition and physical characteristics. As a result of the multiple regression analysis, we obtained a general mathematical model of the dependence of the weight loss of

cauliflower during storage on the content of dry matter, the volume and the porosity of a head.

$$Y = 4.63 - 0.47x_1 + 0.006x_2 + 1.93x_3,$$

where *x*<sub>1</sub> is the content of dry matter, %; *x*<sub>2</sub> is the volume of a head, cm<sup>3</sup>; *x*<sub>3</sub> is porosity, %.

There were similar studies carried out during storage of squashes. The hybrid of squash Arlika F<sub>1</sub> had the porosity of small fruits of 8.5 %, and the porosity of large ones of 13.4 %. The weight loss made up 5.05 and 4.25 %, respectively, during storage. The loss of dry matter varied from 27.1 % in small fruits to 14.1 in large fruits in the structure of losses [35].

Researchers stored fruits of squashes with a diameter of 4.5–6.0 cm at a temperature of 5±1 °C are kept for five days, fruits of squashes with a diameter of 6.1–8.0 cm for 13–16 days, a mixture of the indicated fruit sizes – for 10–12 days, and large non-standard sized fruits (8.1–10.0 cm) – for 18–21 days. The intensity of their moisture evaporation and the structure of weight loss change with the increase in the size of a fruit. Small-sized fruits spend 10–24 % of

Table 3

dry matter from its initial level under different temperature conditions there is the inverse dependence in large fruits [36].

The weight loss of cucumbers correlates with their size during storage. Respiration of cucumbers of the length of 90–110 mm is more intensive in comparison with cucumbers of the size of 111–140 mm, and therefore they spend more dry matter. The ratio of the dry matter consumption to the moisture in the relative weight loss in cucumbers of the length of 9–11 cm was 1:3, and in fruits of the length of 11–14 cm – 1:13.7, that is, there was 13.7 % of moisture per one relative percentage of loss of dry matter (total natural weight loss of mass) [37].

Studies confirmed that the storage of different types of cabbage in perforated film packages preserves their appearance, taste and content of ascorbic acid better [38]. There were similar results obtained at storage of radish. The share of dry matter in the structure of natural weight losses of radish in all variants of the experiment was on average of 27.5 % of dry matter, and there was 72.5 % per share of water. Moreover, if to divide root crops stored in polyethylene packages of different types and root crops stored in cardboard boxes, then the structure of losses has 25.5 % of the share of dry substances and 74.5 % of the share of water [39].

The weight loss of sweet pepper fruits due to water evaporation of water in technically ripe fruits was 88.9 % and 77.9 % during refrigerated and non-refrigerated storage, respectively. The weight loss of Iskorka tomato fruit occurred mainly due to water evaporation and occupied 87.2–89.6 % and 72.4–77.8 % of total weight losses during refrigerated storage and storehouse storage during the years of studies [40].

Reducing of the weight loss of cauliflower is possible due to application of packaging materials in the form of polyethylene packaging (PEP). But packaging of products in polyethylene packages does not stop development of microorganisms. It is possible to solve this problem by processing with the film-coating with antiseptics. Such coating gives possibility to create moisture-retaining and gas-permeable film for each individual item of the product separately. The consequence is inhibition of biochemical processes and



reducing of the expenditure of substances on metabolic processes.

## 6. Conclusions

1. We established that weather conditions during the experimental years were variable. The average daily temperature ranged from 1,743.4 (in 2017) to 2,544.3 °C (in 2015) over the years of studies and it exceeded the upper limit of the optimal amount of 58.9–380.3 °C. HTC was 0.58 in 2015, we consider this period as medium-dry according to the classification by G. T. Selyaninov. The vegetation period was sufficiently wet (GTC=1.10) in 2016. In 2017, this indicator was 0.46, so this period was very dry. The vegetative period of 2016 was optimal for the growth and development of cauliflower plants.

2. Vegetation conditions influenced the weight loss of late-ripening cauliflower heads during storage as follows: greatest natural losses were in 2015 in the control version, they made up 12.8–16.9 %, and the lowest losses were in 2016 – 11.7–13.8 % depending on the hybrid. The difference between hybrids in the years of studies was significant. The natural weight loss of cauliflower heads during the storage without packaging was on average 13.7 % in the Caspian F<sub>1</sub> hybrid, 12.7 % in Santamaria F<sub>1</sub> and 15.5 % in Skywalker F<sub>1</sub> in 2015–2017. We obtained the general regression depen-

dence of the weight loss of cauliflower during storage on weather factors, such as HTC, the average daily temperature, and relative humidity of the air of the vegetation season, according to the results of multiple regression analysis.

3. The intensity of moisture reduction at the storage temperature of cauliflower 1±0.5 °C varied from 0.27 to 9.3 % depending on the method of packaging. At packaging in a stretch film, the intensity of moisture evaporation in all hybrids was the same, it amounted to 0.3 % per day. The perforated stretch film increased the moisture evaporation slightly from 0.37 % in Casper F<sub>1</sub> hybrid to 0.43 in the Skywalker F<sub>1</sub> hybrid. When keeping cauliflower heads open, the ratio of moisture loss to loss of dry matter ranged from 11.2 in Santamaria F<sub>1</sub> heads to 13.2 in Casper F<sub>1</sub> heads. It was 0.23–0.23 at using of PF, and 0.35–0.43 at using of SPF.

4. According to the results of multiple regression analysis, we obtained the general regression dependence of the level of weight loss of cauliflower during storage on weather factors, such as HTC, the average daily temperature and the relative humidity of the vegetation season, and the dependence of the weight loss of cauliflower during storage on dry matter content, a volume and porosity of a head. Regression equations give possibility to forecast the weight loss of cauliflower during storage, depending on weather conditions of the vegetation season and the content of dry matter and physical characteristics of heads.

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