Prediction of persistence conditions for microencapsulated vitamin C

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Abstract. The article aimed to assess the impact of various storage conditions on the shelf life of microencapsulated ascorbic acid as a food supplement for agricultural enterprises. The study involved determining the degree of influence of various aggressive storage conditions (increased humidity, elevated temperature, up to 40-45 °C, with access to sunlight) on the stability of microencapsulated vitamin C. As a result of the study, it was found that microencapsulation of vitamin C in the protective layer of maltodextrin provides Vitamin C persistence under a number of storage conditions. Optimum storage conditions for microcapsules with ascorbic acid: temperature conditions are allowed 20-24 °C, a place protected from light at a relative humidity of 55-60%. During long-term storage, up to 1 year, subject to storage rules, the vitamin C content in the test samples decreased slightly. The findings allow us to expand the possibilities of production and use of microencapsulated vitamin C as an independent product for agricultural enterprises.

1. Introduction
The priority goal of the development of the agro-industrial complex of Russia is to increase the nutritional value of agricultural products and the food industry. Actual technology to achieve this goal is microencapsulation of biologically active substances. Hence, research tasks come down to two main blocks: assessing the quality characteristics of microencapsulated substances and improving microencapsulation technologies. To date, modern food bioengineering has sufficient accumulated experience of research results on the effectiveness of microencapsulation of various biologically active additives to food products, for example, the immobilization of probiotics [1-3], vegetable fats [4, 5], vitamins [6-9]. World studies of encapsulation technologies offer different ways of conducting the microencapsulation process and the characteristics of the necessary equipment.

Among biologically active substances for food fortification, vitamin C (C₆H₈O₆), (ascorbic acid), occupies an important place. Since ascorbic acid is unstable and light, temperature and contact with air can break the bonds in it, therefore, studies are underway to encapsulate it in a protective matrix. In such studies, conclusions were drawn about the stability of encapsulated vitamin C in the finished product and the possibilities of its use in the food industry [10].

Recognizing the importance of the research, the next step should be to study the possibilities and conditions of storage, packaging and transportation of microcapsules for possible introduction in the agricultural industry as an independent product, when enterprises have the opportunity to purchase ready-made microcapsules. In addition, many food industry enterprises have several factories located...
closer to raw materials. Such production complexes will also need to deliver microcapsules to all of its units. The relevance of the optimal storage and packaging of microencapsulated micronutrients has led to the formulation of the goals and objectives of this experimental work.

The aim of this work is to assess the effect of various storage conditions on the shelf life of microencapsulated ascorbic acid.

2. Materials and methods
The experiment included the preparation of microcapsules of ascorbic acid with a protective layer 6 μm thick. Maltodextrin was used as a protective layer. Microcapsules were obtained by applying to the surface of ascorbic acid a fluidized bed of maltodextrin (10% aqueous solution of maltodextrin) according to a procedure similar to that in the studies [11, 12].

In the experiment, the influence of the following aggressive storage factors on the stability of ascorbic acid was investigated: relative air humidity 75-80%, temperature 45-50 °C, with access to sunlight. The total duration of observations was 18 months. Control measurements of samples were made at the beginning of the experiment (after the manufacture of microcapsules), then after 6 and 12 months. Unencapsulated Vitamin C was taken as a control sample.

All test samples of ascorbic acid were packaged in plastic wrap. The amount of vitamin C in each package was 1 mg.

The amount of ascorbic acid was determined by the iodometric method.

The confidence level of statistical data analysis was 0.95 (p≤0.05).

3. Results and discussion
As a result of the study of the influence of aggressive environmental factors on microencapsulated vitamin C, the following conclusions were obtained (table 1):

| Sample              | storage conditions                                                                 | 0 months (background) | 6 months | 12 months | 18 months |
|---------------------|-----------------------------------------------------------------------------------|-----------------------|----------|-----------|-----------|
| Unencapsulated      | температура 20-24°C, относительная влажность воздуха 55-60%, без доступа солнечного света | 100                   | 94       | 89        | 76        |
| Vitamin C           |                                                                                   |                       |          |           |           |
| Microencapsulated   | температура 20-24°C, относительная влажность воздуха 55-60%, без доступа солнечного света | 100                   | 100      | 98        | 96        |
| Vitamin C           |                                                                                   |                       |          |           |           |
| Unencapsulated      | температура 20-24°C, относительная влажность воздуха 75-80%, без доступа солнечного света | 100                   | 96       | 85        | 72        |
| Vitamin C           |                                                                                   |                       |          |           |           |
| Microencapsulated   | температура 40-45°C, относительная влажность воздуха 55-60%, без доступа солнечного света | 100                   | 63       | 47        | 25        |
| Vitamin C           |                                                                                   |                       |          |           |           |
| Microencapsulated   | температура 20-24°C, относительная влажность воздуха 55-60%, с доступом солнечного света | 100                   | 93       | 87        | 76        |
| Vitamin C           |                                                                                   |                       |          |           |           |
| Microencapsulated   | температура 20-24°C, относительная влажность воздуха 55-60%, с доступом солнечного света | 100                   | 87       | 74        | 63        |
| Vitamin C           |                                                                                   |                       |          |           |           |

Table 1. Study of the influence of aggressive storage factors on the persistence of microencapsulated vitamin C, %.
In accordance with the results obtained, it can be concluded that unencapsulated vitamin C is subject to a greater destructive effect of aggressive environmental conditions than microencapsulated vitamin C. The main reason for this is that the microcapsule shell allows protecting vitamin C from the harmful effects of the external environment. At the same time, it was noted that unencapsulated vitamin C reacts more strongly to an increase in temperature, and weaker - to sunlight (see figure 1). An increase in air humidity has practically no negative effect.

**Figure 1.** The dynamics of the reaction of unencapsulated vitamin C to environmental factors.

Microencapsulated vitamin C is also susceptible to environmental factors during storage (figure 2), but to a lesser extent than unencapsulated. The most severe influence is exerted by the temperature regime of storage. An increase in temperature similarly leads to the gradual destruction of vitamin C.

**Figure 2.** The dynamics of the reaction of microencapsulated vitamin C to environmental factors.
Light also has a negative effect on the content of vitamin C. Due to the protective shell, the destructive effect of daylight is reduced. However, with an increase in the shelf life of microcapsules, after 12 months, the negative effect of sunlight increases, vitamin C begins to deteriorate more.

To determine the rate of change in the vitamin C content of unencapsulated and encapsulated, the coefficient of advancing is calculated. It is calculated as the ratio of microencapsulated vitamin C to unencapsulated.

It can be seen from the graph (figure 3) that the rate of decrease in the content of vitamin C unencapsulated is everywhere higher than the encapsulated one. At the same time, elevated storage air temperature has the most damaging effect on vitamin C. Thus, by the end of 18 months of storage, the content of vitamin C of unencapsulated was three times lower than that of encapsulated.

4. Conclusion
As a result of the study, it was found that microencapsulation of vitamin C in the protective layer of maltodextrin ensures the preservation of vitamin C under a number of storage conditions.

Optimal storage conditions for microcapsules with ascorbic acid are as follows: temperature conditions are allowed 20-24 °C, a place protected from light at a relative humidity of 55-60%.

During long-term storage (up to 1 year) subject to storage rules, the vitamin C content in the test samples decreased by less than 2% (p ≤ 0.01) and by 4% (p ≤ 0.05) over 18 months.

Microencapsulation of vitamin C can be an effective way to preserve it. At the same time, compliance with the rules and storage regimen of microcapsules makes available long-term storage (up to 18 months) of microcapsules and its further distribution on the market as a biologically active additive in the production of food products.

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