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THE INFLUENCE OF VARIOUS SUGARS ON THE RHEOLOGICAL PROPERTIES AND STABILITY OF WHEAT DOUGH

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Abstract: *The influence of sucrose, glucose, and fructose on the rheological characteristics and stability of dispersed systems based on wheat dough is investigated. It is shown that the structure-forming ability of sugars depends on their molecular weight and the size of their molecules. According to the effectiveness of influence on the rheological properties of the dough, the sugars can be arranged as follows: sucrose> glucose> fructose. When sucrose is replaced with fructose or glucose, dough viscosity decreases, which is unwanted in the context of its stability and because of some technological issues like the easiness of its transportation. A complex additive containing pectin is proposed to compensate for the reduction in dough viscosity and stability because of the replacement of sucrose by glucose and fructose. Only 0.05 wt % of the natural pectin ensures an increase in the dough viscosity that approaches or exceeds the viscosity of the sucrose-containing compositions. Due to this effect, the technological transportability of the dough is kept within the required range, and the porosity and friability of the pastry is preserved. If the kneaded pastry is kept for 4 h before baking, its partial fermentation leads to a decrease in this favourable effect of pectin on the sensorial qualities of the pastry.*

Keywords: *sucrose, glucose, fructose, wheat dough, viscosity, dough stability*

1. Introduction

Sugar is a constituent component of various dough compositions and many other food items: pastry, beverages, and others. It is necessary to provide the sweetness of confectionery or regular dough, to maintain its nutritional value, and to keep the required value of some technological parameters such as dough viscosity and stability. The latter requirement is important in the context of dough storage and transportation, keeping organoleptic parameters of dough and pastry such as porosity, stability, friability, general shape, and appearance [1 - 3]. Even though regular sugar is the cheapest and the most widely used sweetener, which is required for normal nutrition and functioning of the digestive system and other organs of humans, in many cases, it should be partially or completely substituted by other components because of dietary requirements, individual sucrose intolerance or other reasons [3 - 5]. When sucrose is replaced by other components, the total content of sugars required to keep the sweetness of an item may be greater or lower than that in the item made without sucrose substitutes. Any changes in the dough recipe lead to changes in its mechanical and sensorial properties. This issue must be addressed in order to maintain the normal technological process of the pastry or other items production and to make sure their customer qualities do not deteriorate.

For instance, glucose, fructose, and some other sugars are easier to digest and may be used as sucrose replacement components in some dietary schemes for people suffering from digestion disorders or with other special needs [6, 7]. On the other

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hand, sugars are not only sweeteners but also act as dough-thickening agents, which contribute to its viscosity. It is known that if the weight % concentration of aqueous solutions of sucrose, fructose, and glucose is the same, the viscosity of the former is the greatest, while for the latter, it is the lowest [8, 9]. Therefore, a dependence of dough viscosity, porosity, stability, friability, and other organoleptic qualities on the concentration and nature of sucrose-replacing agents should be clearly established.

In this work, we analyze the dependence of dough viscosity and stability on the concentration of different sugars and possible approaches to compensate for the decrease of the dough viscosity that occurs when replacing sucrose with glucose or fructose.

2. Materials and methods

Regular white wheat flour "Vinnytskyi Mlynar" (produced by the Vinnytsya branch of UkrPromInvest Agro Group, Ukraine), sucrose (white sugar), glucose, fructose, and pectin of various brands were indiscriminately chosen and obtained from local grocery stores. All components were declared by their manufacturers as complying with relevant legal requirements and standards of Ukraine. The dough was prepared using the following recipe: 100 mL of water was added to 200 g of the flour and 5 g of salt. When needed, a required amount of a sugar component was additionally used in the mixture. The mixture was hand-kneaded for approximately 10 minutes or until it no longer sticks to the hands and left for 20 minutes for ripening. Then, the required amount of dough was taken to conduct the experimental investigations.

The effective viscosity of dough was measured using a rotational viscometer "Rheotest-2" by VEB "MLW" (Germany) with the set of cylinders "S and S_3" following the relevant instructions [10]. The effective viscosity (η, Pa·s) was calculated as

$$\eta = \frac{z \times a}{D_r} \times 100, \qquad (1)$$

where z – measuring cylinder's constant, a – shifting angle, deg, D_r – shifting velocity, s^{-1}.

The dough viscosity was measured for the samples containing 0-10 wt % of a sugar, and the sensorial properties of dough were investigated for the samples containing 0-40 % of a sugar. For better reproducibility all experiments were repeated three times, and then the results were averaged. The relative experimental error did not exceed 15 %.

Dough stability was measured using an original set of measuring columns. Each column was 12 mm in diameter and 300 mm long. A 3 g sample of the dough mixture was poured into the column, the initial volume of the mixture was measured, and then a required amount of water consisting of some sugars was added. The dough was left for 4 h at room temperature, and then the height of the swollen dough was measured and compared with its initial value.

3. Results and discussion

The dough can be considered as a viscous multicomponent mixed genuine/colloidal solution. Since it consists of some colloidal and high-molecular solutes, the inner structuring may appear in it, turning this system into a non-Newtonian fluid where the effective viscosity no longer linearly depends on the solute's concentration. Any Newtonian fluid is a more predictable and easily researchable object, and that is why it is important to outline the limits within which the concept of Newtonian fluid applies to dough.

These limits were determined through the investigation of the dependence of dough viscosity on the content of flour at a comparatively low shear speed of 27 s^{-1} (Fig. 1). As seen, this dependence remains more linear up to the flour concentration in the dough of 30 %, and then its pattern becomes non-linear. It means that even if some inner structuring takes place in the dough with a concentration of less than 30 %, it remains unstable and not influential. After 30 %, the structuring becomes more significant and transforms the dough into a non-Newtonian fluid. Based on this result, we planned all further investigation with the 20 % dough, which is expected to exhibit the properties of a more predictable Newtonian fluid.

The influence of the concentration of sugars on the rheological characteristics of dough was investigated on a dough consisting of 20 wt % of flour and kneaded with the 2.5, 5, 7.5, and 10 wt % aqueous solutions of sugars instead of water. As could be expected, the viscosity of all systems increases with a rise in the concentration of all sugars. Sucrose causes this fastest increase in viscosity, followed by a close increase for glucose, while the intensity of viscosity rise in the case of fructose is much weaker (see Fig. 2, black lines).

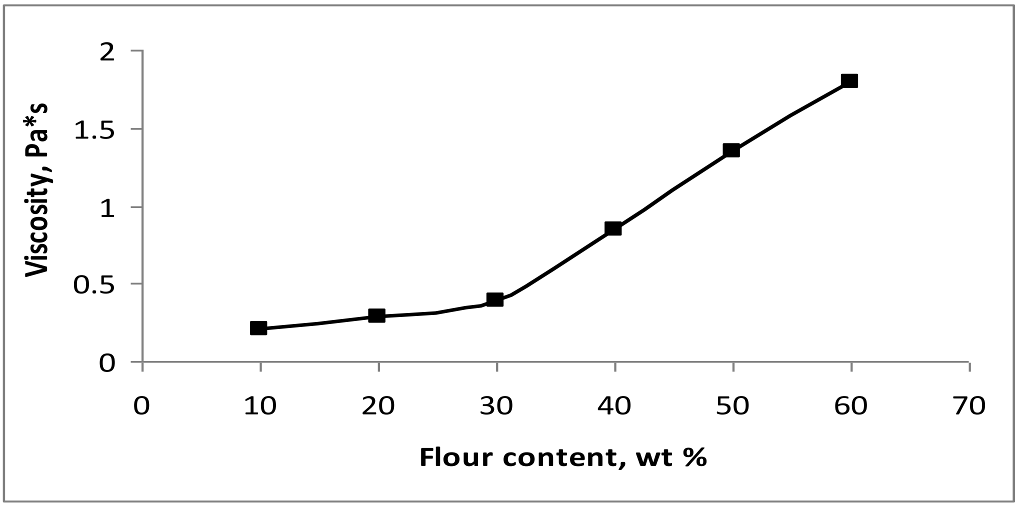

Fig.1. The dependence of the dough viscosity on the content of flour for the shear speed 27 s^{-1}.

It should be noted that in the case of aqueous solutions of the oligosaccharides, their viscosities are arranged differently: the viscosity of sucrose solutions is still the highest, but it is followed by the viscosity of fructose solutions, and then – by glucose solutions [9]. The authors of [11] also reported some decrease in the dough viscosity and elasticity as a result of substituting traditional sucrose with glucose.

As expected, the dough viscosity increases when the solute's concentration rises. A different order of the viscosities of sucrose, glucose, and fructose-containing dough, as compared with the order of their aqueous solutions, can be explained by the different abilities of these sugars to form internal structuring in the dough. In the framework of this assumption, the structuring ability of glucose seems smaller but close to that of sucrose, while for fructose, it decreases more significantly. This assumption can be supported by the dependence of dough viscosity on the shear speed (Fig. 3). The more 'Newtonian' a fluid, the more horizontal the dependence is. As seen in Fig. 3, the fructose dough line becomes practically horizontal at a shear speed greater than 240 s^{-1}, the glucose dough and sucrose dough lines – at 440 s^{-1}. The inner structuring of dough remains stable at any lower shear speed, meaning that the dough cannot be classified as a 'Newtonian' fluid at shear speeds lower than those indicated above for the respective dough types. Therefore, based on our results, the dough sweeteners can be arranged in the following way by their ability to increase the dough viscosity: sucrose > glucose >fructose.

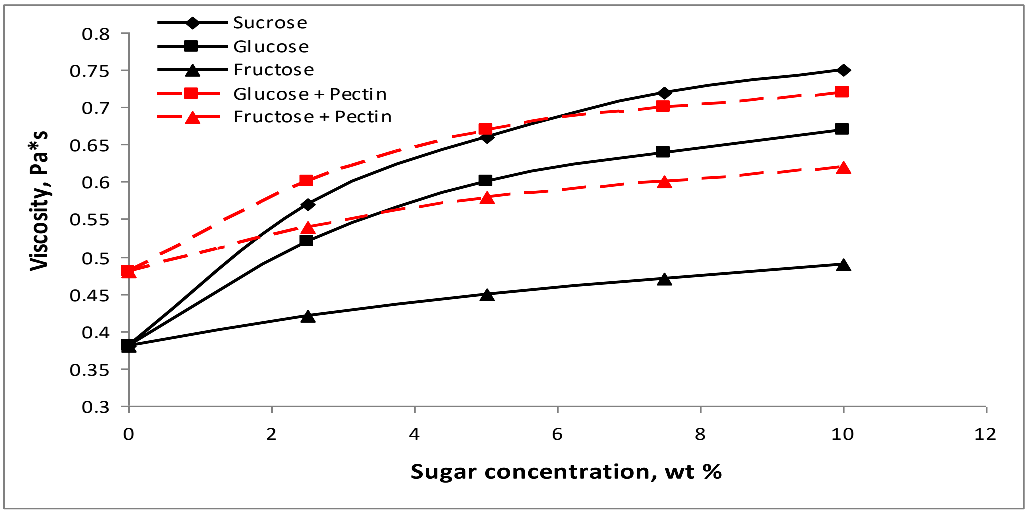

Fig. 2. The dependence of a 20 % flour dough effective viscosity of the content of sugars: sucrose (♦), glucose (■), fructose (▲), glucose + 0.05 % of pectin (■), and fructose + 0.05 % of pectin (▲).

It is well known that pectin can form branched spatial structures in solutions, leading to an increase in their viscosity [8, 12]. That is why it can be considered as a low-concentrated addition to the glucose and fructose dough to keep its viscosity and friability. It was found that just 0.05 % of pectin results in a significant increase in the dough viscosity, which brings it closer to the values of glucose and sucrose dough (Fig. 2, red lines). Therefore, this compound can be used as a dough component to prevent the deterioration of its viscosity because of the partial replacement of sucrose by glucose and, especially, fructose.

Another issue is related to the substitution of sucrose with glucose or fructose: it affects the dough's friability, stability, and porosity – they may also deteriorate as a result of this substitution [13]. To evaluate this effect on our dough and to check its possible mitigation by the addition of 0.05 % of pectin, we compared the height of the dough samples containing different amounts of sucrose, glucose, and fructose with and without pectin (Fig. 4, 5).

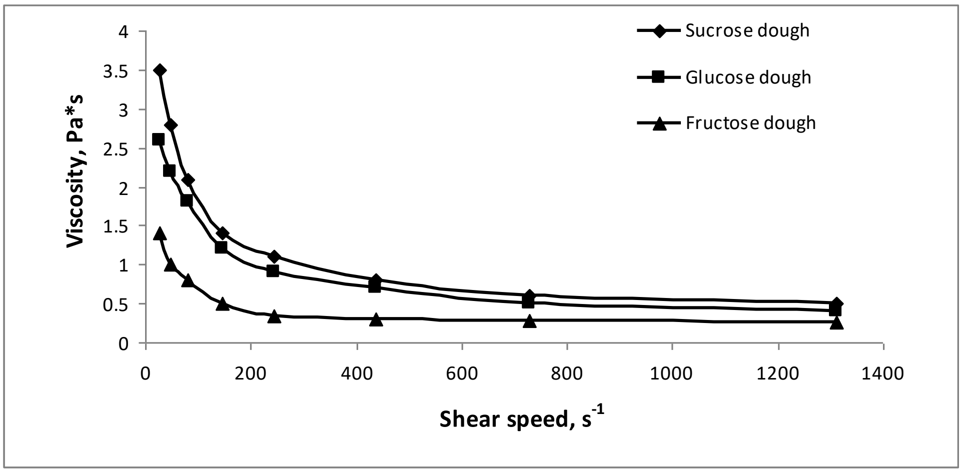

Fig.3. Dependence of the effective viscosity of a 20 % flour dough on the shear speed: (♦) – 10 % of sucrose, (■) – 10 % of glucose, and (▲) – 10 % of fructose.

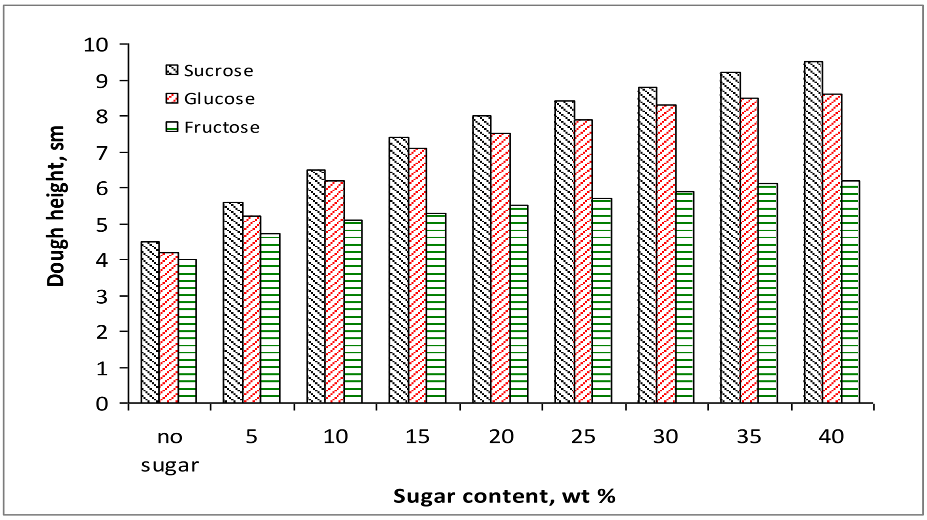

Fig.4. Comparison of the height of dough samples made with sucrose, glucose, and fructose.

As seen in Fig. 4 and 5, pectin increases the stability and height of the dough. In the case of no-sugar-dough, the height of all three samples becomes closer, and in the case of the dough consisting of some sugars, its height and stability significantly increase and, therefore, this addition can be recommended as an extra component to be added to the recipes containing glucose and, especially, fructose instead of sucrose. Such pectin-containing dough compositions turn out to be more stable and porous, and their sensorial properties are not significantly impaired compared to those of the pectin-free glucose and fructose dough compositions.

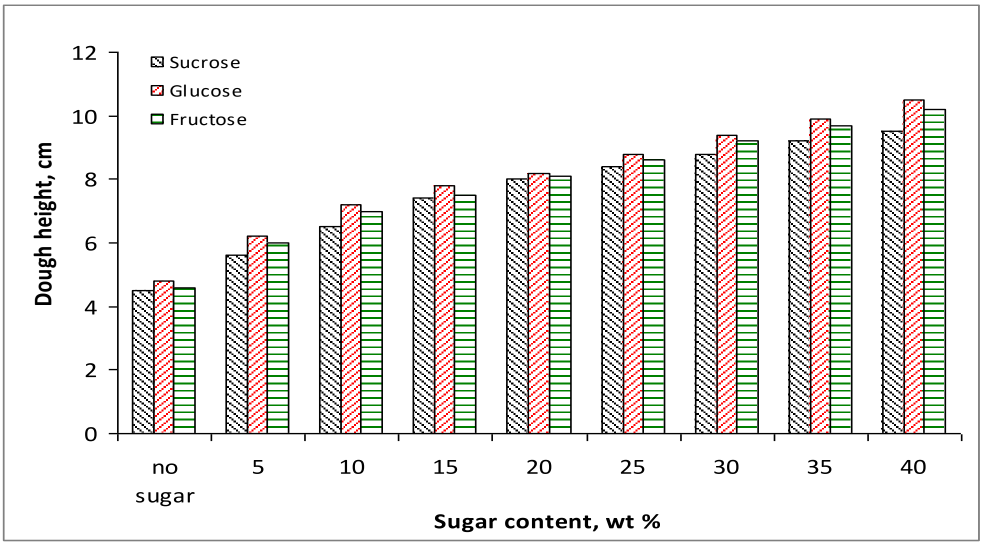

Fig.5. Comparison of the height of dough samples made with sucrose, glucose, fructose, and 0.05 % of pectin.

On the other hand, it should be understood that these effects (deterioration of the dough porosity and stability and their restoration by pectin) are more influential in the short-term range.

When dough, especially the leavened compositions, is left for a longer time, the yeasts hydrolyze sucrose to fructose and glucose, and the difference in the relevant dough compositions gradually decreases and disappears.

4. Conclusion.

Natural sugars affect the dough quality when added to its composition. Sucrose, glucose, and fructose increase the dough's viscosity, and the influence of sucrose is the most significant, followed by glucose and then fructose. When 0.05 % of pectin is added to the glucose and fructose dough compositions, their viscosity increases and approaches or even exceeds (for the contents of sugars below 5 %) those for the corresponding sucrose-containing compositions. These results are important in the context of keeping technological parameters and sensorial qualities of dough and pastry.

Dough porosity and stability can also be improved by the addition of 0.05 % pectin when sucrose is substituted by glucose and/or fructose. Moreover, the height of the samples containing glucose, fructose, and pectin is greater than that of the corresponding sucrose/pectin samples. Long fermentation of the dough (for 4 h or more) diminishes this effect and smoothes the dough height difference.

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