CHOICE OF OPTIMAL HEATING CONDITIONS FOR THE INFRARED IRRADIATION OF GRAIN

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Analysis of the transmission spectra of dried material obtained from the principal anatomical elements of various kinds of grain has shown that the embryo has a selective response in the near infrared, which should be taken into account in selecting a radiator and in checking the temperature regime during the heating process.

Recently considerable progress has been made in the use of infrared radiation as a means of heating grain for various purposes.

However, the literature [1, 5] refers to a number of difficulties associated with a lack of information on the spectral properties of grain, which need to be taken into account in choosing the type of infrared radiator and the optimal heating conditions.

The choice of infrared radiator should be based on the method of accurate selection of the spectral region of the radiation employed relative to the spectral transmission properties on the treated material. Especially important is the choice between "bright" and "dark" radiation. This problem can be settled by examining the transmission spectra of the grain and the absorbed water.

We investigated the optical properties of dry grain material during the 1962–1963 period using a UR-10 spectrophotometer in the range 5000–400 cm^{-1} (2–25 μ) and an IKS-14 instrument in the range 13 333–5000 cm^{-1} (0.75–2 μ). Grain has three principal anatomical elements: the seed coat, the farinaceous part or endosperm, and the embryo. After dampening, the grain was separated into its anatomical elements, which were then dried to constant weight in a desiccator with silica gel at 35° C.

In order to decide upon the method of preparation of specimens of the anatomical components for analysis we used the seed coats of corn [3]. Two methods were compared: compressing the test material in a certain concentration into KBr pellets and the preparation of a "transparent" film. From the seed coat removed from the macerated grain we cut out the part that was thinnest and most transparent in visible light in the form of a strip somewhat wider than the spectrophotometer beam. The strip was smoothed and dried under ordinary room conditions. Then in order to remove as much as possible of the residual moisture the film was placed in a desiccator with silica gel for about 24 hours, until its weight became constant. The film thus dried was mounted in a cell resting on black lightproof paper in which an opening was cut to match the width of the spectrophotometer beam; this prevented twisting of the film during analysis due to thermal deformation.

After the transmission curve D(ν) had been recorded, the film was finely ground in a vibratory ball mill at 3000 vibrations/min for 5 min. The dry material thus obtained was molded into pellets with ground potassium bromide. The concentration of test material in the pellet was selected so that under optimal instrument operating conditions it was possible to obtain a well-resolved transmission spectrum. The optimal concentration was 0.9%.

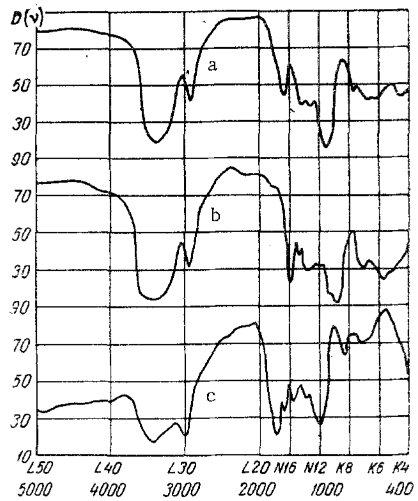

Fig. 1. Infrared transmission spectra of the principal anatomical elements of wheat grain: a) seed coat, b) endosperm, c) embryo.

A comparative analysis of the spectra thus obtained shows that in order to obtain the spectral transmission curve of dry grain material with the object of selecting the optimal infrared heating conditions preference may be given to the method of pelletizing the test substance with potassium bromide.

Figure 1 shows the infrared transmission spectrum of the dry material obtained from the principal anatomical components of wheat grain. The curves for other types of grain and seeds, for example, corn, peas, etc., are generally similar.

The recording conditions for the UR-10 instrument were as follows: slit program 8, recording speed 150 cm^{-1}/min, total amplitude recording time 50 sec, recording scale 4 mm/100 cm^{-1}, amplification 5.5, band pass setting 3, time constant 2. In all cases the concentration of the test substance was 0.9%.

From the spectra obtained we see that in the region 2700–1700 cm^{-1} all three components have a broad band of good transmission of the same intensity. In the region 3600–2700 cm^{-1} there is a strong absorption band, which also affects all the components in the same degree. However, in the shortwave region 5000–3600 cm^{-1} the seed coat gives the best transmission, the transmission of the endosperm being somewhat reduced relative to that of the seed coat. In the same region the embryo is characterized by a sharp drop in transmission as compared with the other elements of the grain.

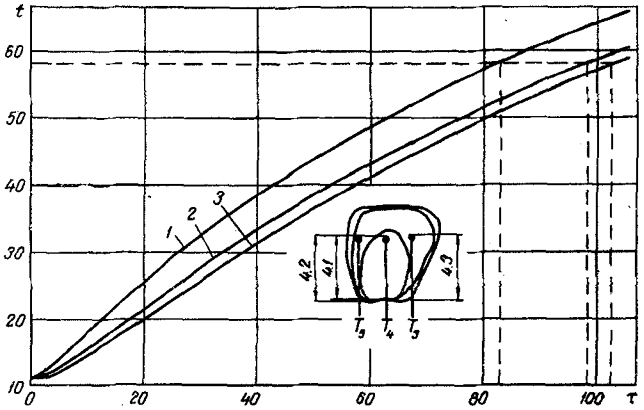

Fig. 2. Dynamics of the temperature regime in an individual grain heated by an infrared source (t in °C, τ in sec): 1) for T_4; 2) T_3; 3) T_5 (T_4 is the thermocouple introduced into the embryo region; T_3 and T_5 are the thermocouples in the farinaceous part of the grain).

It appears that the embryo possesses enhanced thermal sensitivity to shortwave infrared radiation owing to its distinctive biochemical structure. This can be judged from the above-mentioned reduced transmission in the near infrared, which is evidently attributable to the more intense scattering and absorption of radiant energy in the embryo. Consequently, the shortwave part of infrared radiation of relatively high spectral intensity penetrates a much lesser distance into the embryo than, for example, into the farinaceous part of the grain. Consequently, heating of the interior of the grain, to which the radiation does not penetrate, must depend mainly on heat conduction, which leads to a surface concentration of heat in the region of the embryo. Moreover, because of the differences in biochemical structure we may also assume that there is a difference in heat capacity, which probably to some extent also favors a more rapid increase in temperature in the embryo. Thus, in the region of the embryo heated primarily by shortwave infrared radiation, a considerable concentration of heat develops in the surface layer, causing, in the event of overheating, surface burning and thermal damage to the relatively small mass of the embryo.

In order to confirm this conclusion we carried out additional experiments to measure the dynamics of the temperature regime in the different parts of dry grain heated with infrared radiation.

1. We introduced into the region of the embryo and the endosperm miniature copper-constantan thermocouples, arranged at the same depth. The spectral intensity distribution of the source was selected with the maximum in the region 1–2 μ. The variation of temperature in the region adjacent to the thermocouples was recorded as a function of time by means of a Zeiss loop galvanometer with an automatic photorecorder. The nature of the curves obtained (Fig. 2) indicates that the temperature in the region of the embryo is higher than that in the region of the farinaceous part of the grain. The temperature difference in the example presented is 8° C. There is also quite a considerable difference in the times required to heat the embryo and the farinaceous part of the grain to the same temperature: in the given example the embryo reached a temperature of 58° C almost 20 sec before the rest of the grain. The slightly higher temperature in the region of thermocouple No. 3 is attributable to the presence on the surface of the grain turned toward the radiator of a relatively large flat surface perpendicular to the radiant flux.

2. A certain amount of corn was irradiated under conditions similar to those described above. The grain was arranged in a simple layer, uniformly on a flat surface, with the embryo toward the radiator and heated until visible burns appeared. Observations showed that it is primarily the embryo that is overheated as indicated by the fact that the burns are located chiefly in this region of the grain. Figure 3 (9, 10, 11, 12) shows the irradiated grain with burns in the region of the embryo.

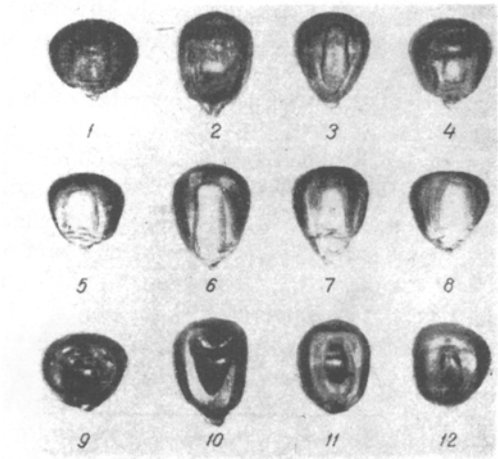

Fig. 3. Grain irradiated with a "dark" radiator with uniform burns over the entire surface turned toward the radiator (1, 2, 3, 4); unirradiated grains (5, 6, 7, 8), and grain irradiated with a "bright" radiator with burns in the region of the embryo (9, 10, 11, 12). Twofold magnification.

3. The spectral distribution of the radiation energy of the source was selected with the maximum radiation intensity in the region 4.5–5 μ. In this case the burns appear primarily in that part of the grain that is closest to the radiator, more correctly, on the part of the surface perpendicular to the radiant flux. Burns appear simultaneously on the seed coat and the endosperm and in the region of the embryo, which confirms that the spectral transmission curve is identi-

cal for all the components in the above-mentioned region. Grain thus irradiated is shown in Fig. 3 (1, 2, 3, 4), which for comparison (5, 6, 7, 8) also shows grain not subjected to infrared heating.

From analyzing the spectral transmission curves obtained for the seed coat, endosperm and embryo, as well as the additional experiments confirming the selective response of the embryo to the shortwave part of the infrared radiation, we conclude that to equalize the temperature differences that develop in the radiant heating of grain it is necessary to select a source with maximum radiation intensity in the region in which all the components have the same transmission. In the case of moist grain it is also necessary to take into account the spectral properties of the water, which have a definite effect on the heating process. A comparison of the spectral transmission curves for the principal anatomical elements of grain and water shows that from the standpoint of uniform deep heating of the grain it is best to use a radiator with a maximum radiation intensity in the region 2700–1700 cm^{-1}. In this case owing to the good transmission the radiant energy is converted into heat at a relatively great depth in all the components of the grain, which gives more uniform heating.

It is clear from Fig. 4 that the best radiator from the standpoint of uniform heating is a low-temperature "dark" radiator, the use of which considerably reduces the embryo selectivity effect in the near infrared and hence reduces the probability of thermal damage during the treatment of seed grain. On the other hand, in order to effectively destroy the harmful saprophytic microflora chiefly found on the surface of the embryo [9] it is clear that brief exposure to a high-temperature "bright" infrared radiator may be more effective. However, in this case it should be kept in mind that owing to the above-mentioned difference in the transmission of the anatomical components in the near region of the spectrum due to differences in biochemical structure the use of a "bright" radiator may harm the embryo, even though the temperature of the rest of the grain does not reach the maximum permissible value.

The results obtained permit the following conclusions:

1. In specifying the maximum permissible temperature for grain heated with infrared rays, in order to avoid thermal damage to the embryo, it is necessary to take into account its selective response to the shortwave component of the emission spectrum of the source.

2. In order to check the maximum permissible grain temperature the temperature probe should be introduced into the embryo region.

3. In order to obtain more uniform heating of all the components of the grain and reduce the temperature difference between the embryo and the endosperm during radiant heating it is necessary to use a "dark" low-temperature infrared radiator with a spectral emission maximum corresponding to the central part of the high transmission band common to all the components of the grain (2700–1700 cm^{-1}).

4. If high-temperature "bright" infrared radiators are employed they should be used very cautiously with consideration for the selective properties of the embryo.

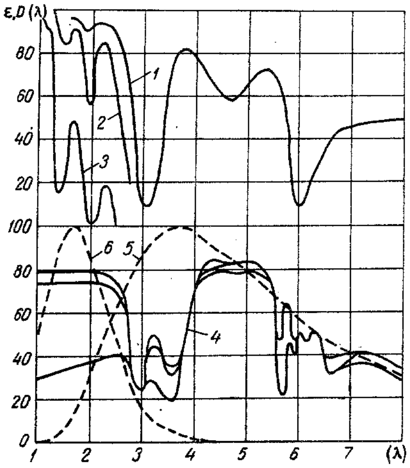

Fig. 4. Combination of spectral transmission curves of the principal anatomical elements of corn grain and water (according to Ashkinazi et al. [1]), and the emmission spectra of "bright" and "dark" radiators (according to Brügel [2]): 1, 2, 3) for water films 0.01, 0.05 and 0.6 mm thick, respectively; 4) for seed coat, endosperm and embryo; for "dark" radiator, T = 525° C; 6) "bright" radiator, T = 1950° C (along the ordinate axis ε, D(λ) in %, along the axis of abscissas (λ) in μ).

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