


Abstract. The Florida commercial vegetable industry is large and diverse and the value of vegetable production in the state of Florida is over 1.5 billion dollars annually. Most of these vegetable crops are produced for the fresh market and require proper post harvest control to maintain quality and reduce spoilage. The ambient environment which the freshly harvested vegetables are exposed has a very significant effect on the post harvest life of these perishable commodities. Psychrometrics is the measurement of the heat and water vapor properties of air. Commonly used psychrometric variables are temperature, relative humidity, dew point temperature, and wet bulb temperature. These terms may be familiar but they are often not well understood. A better understanding of psychrometrics will allow packinghouse operators to improve post harvest cooling and storage conditions for fresh vegetables. This article presents the relationship of psychrometric variables, considers their effect on perishable commodities, and reviews how they can be measured and used as a management tool.

Introduction

Psychrometrics deals with thermodynamic properties of moist air and the use of these properties to analyze conditions and processes involving moist air (ASHRAE, 1989; Henderson and Perry, 1980). Commonly used psychrometric variables are temperature, relative humidity, dew point temperature, and wet bulb temperature. While these may be familiar, they are often not well understood (Gaffney, 1978; Kader et al., 1985; Grierson, 1964; Grierson and

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PSYCHROMETRICS AND POST HARVEST OPERATIONS

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Psychrometric Variables

Atmospheric air contains many gaseous components as well as water vapor. Dry air is a mixture of nitrogen (ca. 78%), oxygen (ca. 21%), argon, carbon dioxide, and other minor constituents (ca. 1%). Moist air is a two-component mixture of dry air and water vapor. The amount of water vapor in moist air varies from zero (dry air) to a maximum (saturation) which depends on temperature and pressure. Even though water vapor represents only 0.4 to 1.5% of the weight of the air, water vapor plays a very significant role in the effect of air conditions on the post harvest life of perishable commodities.

The physical and thermodynamic properties of moist air (psychrometric variables) are related by a number of physical laws. These properties of moist air can be expressed in terms of many different variables. Psychrometric properties important to post harvest horticulture include dry bulb temperature, wet bulb temperature, dew point temperature, relative humidity, humidity ratio, enthalpy, and specific volume.

The dry bulb temperature (db) is the actual air temperature measured with a common thermometer or thermocouple. The wet bulb temperature (wb) is measured with a common thermometer or thermocouple with the bulb or junction covered with a water-moistened wick and in a moving stream of ambient air. Evaporation from the wick attains a steady state, in which sensible heat from the surroundings provides heat of vaporization. Air flow past the bulb must be high enough to prevent significant change in the ambient air temperature. Evaporation of water cools the bulb. The
drier the surrounding air, the greater the rate of evaporation and the lower the wet bulb temperature. The wet bulb temperature is the lowest temperature to which an air mixture can be cooled solely by the addition of water with absolutely no heat removed. The process of cooling an air mixture with the addition of water and with no removal of heat is called "evaporative cooling."

If air is cooled without changing its moisture content, it will lose capacity to hold moisture. If cooled enough, it will become saturated, and if cooled further, will lose water in the form of dew or frost. The temperature that causes condensation is called the dew point temperature (dp) if it is above 0°C (32°F) or the frost point temperature if it is below 0°C (32°F).

Relative Humidity (RH) is the best known and perhaps the most widely used (and misused) term for expressing the water vapor condition of moist air. RH is defined as the ratio of the water vapor pressure in the air to the saturation vapor pressure at the same temperature, and is normally expressed as a percent.

The Humidity ratio (or mixing ratio or absolute humidity) is the ratio of the weight of water vapor in a moist air sample to the weight of dry air contained in the sample. It is usually expressed in terms of kg water per kg dry air (lb water per lb of dry air). This property is very useful since it allows two conditions to be compared in terms of the humidity gradient between the conditions. Water vapor will move from a condition with a higher moisture level to a condition with a lower moisture level.

The enthalpy is the heat energy content of an air-water vapor mixture. The energy is both sensible (indicated by dry bulb temperature) and latent heat of vaporization (energy content of the water vapor). This variable is important for engineering calculations such as estimating the tons of refrigeration required to cool perishable produce. Enthalpy will not be emphasized since the purpose of this paper is the use of psychrometric variables to analyze environmental conditions and then determination of required action to optimize the conditions.

The specific volume of a moist air mixture is defined as the volume of the mixture per unit weight of dry air and is expressed in terms of m³ per kg dry air (ft³ per lb dry air) and is also more important for engineering calculations than analysis of environmental conditions.

Psychrometric Chart

The psychrometric chart is a graphical representation of the relationships between these variables (Figure 1). Although complicated in appearance, use of this chart to establish a state point is easily mastered. The charts can be obtained from ASHRAE and several refrigeration equipment manufacturers in pads like graph paper.

The dry bulb temperature is the horizontal axis of the chart. The vertical axis located on the right side of the chart is the humidity ratio. Two of the variables must be known to establish a state point from which other variables can be readily obtained as shown in Figures 1 and 2.

The maximum amount of water vapor that air can hold at a specific temperature is given by the left most, upward-curved line in Figure 1. It is noted that air holds increasingly more water vapor at increasing temperatures. As a rule of thumb, the maximum amount of water that the air can hold doubles for every 11°C (20°F) increase in temperature.

This line in Figure 1 is also called the 100% RH line. A corresponding 50% RH line is approximated by the points which represent the humidity ratio when the air contains one-half of its maximum water vapor content. The other relative humidity lines are formed in a similar manner.

The relative humidity without some other psychrometric variable does not determine a specific moist air condition on the chart and is not very meaningful. As will be shown, 80 percent relative humidity at 0°C (32°F) is a much different air condition than 80 percent relative humidity at 20°C (68°F).

Another commonly used psychrometric variable is wet bulb temperature. On the chart (Figure 1) this is represented by lines that slope diagonally upward from right to left. In practice, wet bulb lines are used to determine the exact point on the psychrometric chart which represents the air conditions in a given location as measured by a psychrometer, which will be described below. The intersection of the diagonal wet bulb temperature line (equal to the temperature of a wet bulb thermometer) and the vertical dry bulb temperature line defines the temperature and humidity conditions of air.

The dew point temperature for a given state point is found by the intersection of a horizontal line drawn through the state point and the 100% RH or saturation line (Figure 1).

Vapor pressure is not shown on all psychrometric charts, but is an important concept in handling perishables. It is

a function of the humidity ratio and temperature of the air. As humidity ratio and temperature increase, vapor pressure increases.

Figure 2 illustrates the properties of air that can be determined when the dry bulb and wet bulb temperature are known (73°F db and 52°F wb for example), which for this case are 20% RH, 30°F dp, 0.0035 lb water per lb of dry air humidity ratio, 21.3 Btu/lb dry air enthalpy and 13.5 ft³ per lb dry air specific volume.

Figures 3 and 4 are psychrometric charts in English and metric units, respectively, which will help to illustrate the meaning of various terms.

Psychrometric charts and calculators are based on a specific atmospheric pressure, usually a typical sea level condition. Precise calculations of psychrometric variables will require adjustment for barometric pressures different from those listed on a particular chart being used. The ASHRAE Handbook (ASHRAE, 1989) listed in the cited references provides more information. Most field measurements will not require adjustment for pressure.

Effect of Psychrometric Variables on Perishable Commodities

Temperature

Air temperature is the most important variable because it tends to control the flesh temperature of perishable commodities. All perishables have an optimum range of storage temperatures. Above the optimum, they respire at unacceptable high rates and are more susceptible to ethylene and disease damage. In fact, horticultural commodities respire at rates which double, triple, or even quadruple for every 10°C (18°F) increase in temperature (Kader et al., 1985). Temperatures below the optimum will result in freezing or chilling damage. Accurate control of temperature during precooling and storage is vitally important in maintaining maximum shelf-life and quality.

Humidity Ratio/Vapor Pressure

The rate of moisture loss from a perishable commodity is primarily controlled by the difference in vapor pressure between the air in the intercellular spaces of plant material and the air surrounding it. As indicated above, vapor pressure increases as the air moisture content (humidity ratio) and air temperature increase. The air in fresh plant material is nearly saturated or, in other words, is close to 100% RH. Therefore, the humidity ratio of this air is determined solely by the temperature of the plant material. From the psychrometric chart, it is apparent that low temperatures result in low humidity ratios and high temperatures cause high humidity ratios.

Consider several examples of how the drying of perishables is influenced by vapor pressure (humidity ratio) differences. If sweet corn were precooled to 0°C (32°F) [Point A, Figures 3 and 4] and placed in a refrigerated room with saturated air at 0°C (32°F) [also Point A, Figures 3 and 4], the sweet corn would not lose moisture because the humidity ratio and temperature of the air in the sweet corn and the surrounding air are the same. However, if the sweet corn were at 20°C (68°F) [Point B, Figures 3 and 4] because it was not precooled before being placed in the same refrigerated room, the air in the sweet corn would have a high vapor pressure (high temperature and humidity ratio) compared to the refrigerated air, causing the sweet corn to dry. If the sweet corn were precooled to 0°C (32°F) [again Point A, Figures 3 and 4] but the refrigerated air were at 70% RH [Point C, Figures 3 and 4], drying would also occur because the refrigerated air is at a lower humidity ratio than the saturated air in the sweet corn. However, the rate of moisture loss is much greater when the sweet corn is not precooled than when the sweet corn is at the storage temperature but the storage room air is not saturated. For this example, the difference in humidity ratio between the air in the sweet corn and the storage air is over nine times more when the sweet corn is not precooled than when it is cooled and put in unsaturated storage air.

Drying of perishables in refrigerated storage is reduced by decreasing the difference in humidity ratio (vapor pressure) between air in the perishable commodity and air surrounding it. Total moisture loss is reduced by reducing the time of exposure to this difference in humidity ratio by cooling the product close to the surrounding air temperature as rapidly as possible and by maintaining the condition of the surrounding air as close to saturation as possible. Both the temperature of the commodity and humidity ratio in the surrounding air must be controlled. It is important that these variables be known (measured) so proper control actions can be implemented by managers.

Fig. 3. Psychrometric chart in English units.

Fig. 4. Psychrometric chart in metric units.

Relative Humidity

Relative humidity is a commonly used term for describing the humidity of the air but is not very meaningful without knowing the dry bulb temperature of the air. These two variables allow the determination of humidity ratio, which is a better index of the potential of desiccation. For example, as noted above, the humidity ratio of air at 80% RH and 0°C (32°F) [Point D, Figures 3 and 4] is much less than the humidity ratio of air at 80% RH at 20°C (68°F) [Point E, Figures 3 and 4]. In the example above, if the sweet corn were cooled to 10°C (50°F) [Point F, Figures 3 and 4] and the refrigerated air was at 0°C (32°F) and 100% RH (again Point A, Figures 3 and 4), drying would also occur because the refrigerated air is at a lower humidity ratio than the saturated air in the sweet corn. Therefore 100% RH alone does not mean there is no moisture loss potential. To further illustrate confusion that use of relative humidity alone can create, consider a cold storage room running at 2°C (35°F) and 100% RH [Point G, Figures 3 and 4] exposed to an outside air condition of 23°C (72°F) and 50% RH [Point H, Figures 3 and 4]. Considering % RH only, there is an apparent 2 to 1 moisture gradient from the storage room atmosphere outward toward the ambient conditions, while considering the humidity ratio, the actual moisture gradient is 2 to 1 from the ambient conditions inward toward the storage room atmosphere. Use of the psychrometric chart ascertains the direction of potential water vapor migration.

Dew Point Temperature

Condensation of liquid water on perishables and on container surfaces can be a factor in causing disease problems and degradation of container strength. If a commodity is cooled to a temperature below the dew point temperature of the outside air and brought out of the cold room, condensation will form. This can occur when the product is exposed to ambient conditions between the precooler and the cold storage and the cold storage and refrigerated trucks.

Condensation on the perishables, containers, and walls of the storage room can also occur in storage if air temperatures fluctuate too greatly. Another form of condensation occurs in the storage room as the air in the room is circulated over the evaporator cooling coils of the refrigeration system. The temperature of the cooling coil is usually lower than the return air. As a consequence, the air is cooled below the dew point temperature and moisture condenses and is removed from the cold storage (drain pan). Unless moisture is added by a humidification system, the moisture condensed on the coils will be replaced by moisture from the product in storage. To reduce the moisture loss due to condensation on the cooling coils, the temperature difference between the return air and the coil must be reduced. This can be accomplished by using sufficiently large coil surface area. This will increase the cooling system cost but is the best way to maintain high humidity levels.

Measurement of Psychrometric Variables

All psychrometric properties of air can be determined by measuring two psychrometric variables (three, if barometric pressure is considered). For example, if wet and dry bulb temperatures are measured, then relative humidity, humidity ratio (vapor pressure), dew point, and so on, can be determined with the aid of a psychrometric chart. While many variables can be measured to determine the psychrometric state of air, dry bulb temperature, wet bulb temperature, dew point temperature, and relative humidity are most commonly measured.

Dry Bulb Temperature

Dry bulb temperature can be simply and inexpensively measured by a mercury-in-glass thermometer. The thermometer should be marked in divisions of at most 0.2°C (0.3°F) divisions if the thermometer is used in conjunction with a wet bulb thermometer for determining cold storage air conditions. The thermometer should be shielded from radiant heat sources such as motors, lights, external walls, and people. The shielding can be accomplished by placing the thermometer so it cannot "see" the warm object or protecting it with a radiant heat shield assembly.

Hand-held thermistor, resistance bulb, or thermocouple thermometers can also be used. They are more expensive than a mercury-in-glass thermometer but are not necessarily more accurate. A hand-held thermocouple thermometer offers several advantages including fast response time, durability, and flexibility. An instrument of adequate accuracy can be purchased from a number of agricultural and general supply catalogs for $100 to $250 depending on options and accessories. These instruments are equipped with a sharp probe allowing them to be used for pulp temperature measurement, which is very important in determining initial and final precooling temperatures. In addition to portable sensors, thermocouple leads can be extended to some central location for remote monitoring but would require additional initial cost for leads and multichannel capability. Inexpensive alcohol-in-glass and bi-metallic dial thermometers (meat thermometers) are not recommended due to limits on accuracy, inadequate calibration, and slow response time.

Wet Bulb Temperature

The use of a wet bulb thermometer in conjunction with a dry bulb thermometer is a very common method of determining the state point on the psychrometric chart. Such an instrument, called a psychrometer, consists of a pair of matched temperature sensors, one of which is maintained in a wetted conditions. The wet bulb thermometer is basically an ordinary glass thermometer (although electronic temperature sensing elements can also be used) with a wetted, cotton wick secured around the reservoir. Air is forced over the wick causing it to cool to the wet bulb temperature. The wet and dry bulb temperatures together determine the state point of the air on the psychrometric chart allowing all other variables to be determined.

A psychrometer is a valuable instrument for evaluating the conditions inside a cold storage room. Several types of psychrometers are available from a number of agricultural and general supply catalogs. A sling psychrometer consists of the dry and wet bulb thermometers and a handle for rotating the psychrometer in order to provide the necessary air flow for adequate evaporation. Prices range from $50 to $200. A portable psychrometer replaces the handle with a battery powered fan and is available in the price range of $125 to $200.


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An accurate wet bulb temperature reading is dependent on: (1) sensitivity and accuracy of the thermometer, (2) maintaining an adequate air speed past the wick, (3) shielding the thermometer from radiation, (4) use of distilled or deionized water to wet the wick, and (5) use of a cotton wick.

The thermometer sensitivity required to determine humidity accurately varies according to the temperature range of the air. At low temperatures, more sensitivity is needed than at high temperatures. For example, at 65°C (149°F) a 0.5°C (0.9°F) error in wet bulb temperature reading results in a 2.6 percent error in relative humidity determination, but at 0°C (32°F) a 0.5°C (0.9°F) error in wet bulb temperature reading results in a 10.5 percent error in relative humidity measurements (Kader et al., 1985). In most cases, absolute calibration of the wet and dry bulb thermometer is not as important as ensuring they produce the same reading at a given temperature. For example, if both thermometers read 0.5°C (0.9°F) low, this will result in less than a 1.5 percent error in relative humidity at dry bulb temperatures between 65°C (149°F) and 0°C (32°F) (at a 5°C (9°F) difference between dry and wet bulb temperatures) (Kader et al., 1985). Before wetting the wick of the wet bulb thermometer, both thermometers should be operated long enough to determine if there is any difference between their readings. If there is a difference and the thermometers must be used, one is assumed correct and the reading of the other adjusted accordingly when determining relative humidity.

The rate of evaporation from the wick is a function of air velocity past it. A minimum air velocity of about 3 m per sec (500 ft per min) is required for accurate readings. An air velocity much below this will result in an erroneously high wet bulb reading. Wet bulb devices that do not provide a guaranteed air flow, such as those that sit on a desk, cannot be relied on to give an accurate reading.

As with the dry bulb thermometer, sources of radiant heat such as motors, lights, and so on, will affect the wet bulb thermometer. The reading must be taken in an area protected from these sources of radiation or thermometers must be shielded from radiant energy.

A buildup of salts from impure water or contaminants in the air will affect the rate of water evaporation from the wick and result in erroneous data. Distilled or deionized water should be used to moisten the wick and the wick should be replaced if there is any sign of contamination. Care should be taken to ensure that the wick material has not been treated with chemicals such as sizing compounds that would affect the water evaporation rate.

In general, properly designed and operated wet and dry bulb psychrometers can operate with an accuracy of less than 2 percent of the actual relative humidity. Improper operation will greatly increase the error.

Relative Humidity

Direct relative humidity measurement usually employs an electric sensing element or a mechanical system. Electric hygrometers operate using substances whose electrical properties change as a function of their moisture content. As the humidity of the air surrounding the sensor increases, its moisture increases proportionally, affecting the sensor's electrical properties. These devices are more expensive than wet and dry bulb psychrometers, but their accuracy is not as severely affected by incorrect operation. An accuracy of less than 2 percent of the actual humidity is often obtainable. Sensors will lose their calibration if allowed to become contaminated, and some lose calibration if water condenses on them. Most sensors have a limited life. Relative humidity instruments are not recommended for use in the harsh conditions found in commercial packinghouses. Mechanical hygrometers usually employ human hairs as a relative humidity sensing element. Hair changes in length in proportion to the humidity of the air. The hair element responds slowly to changes in relative humidity and is not dependable at very high relative humidities. These devices are acceptable as an indicator of a general range of humidity but are not especially dependable for accurate relative humidity measurement.

Dew Point Indicators

Two types of dew point sensors are in common use today: a saturated salt system and a condensation dew point method. The saturated salt system will operate at dew points between -12° to 37°C (10° to 100°F) with an accuracy of less than 1°C (2°F). The system is lower in cost than the condensation system, is not significantly affected by contaminating ions, and has a response time of about 4 minutes. The condensation type is very accurate over a wide range of dew point temperatures (less than 0.5°C (0.9°F) from -73° to 100°C (-100° to 212°F)). A condensation dew point hygrometer can be expensive.

There are a variety of other methods for measuring psychrometric variables (Gaffney, 1978). Some are extremely accurate and have some characteristics which make them suited to particular sampling conditions. However, most are not commercially available and are used primarily as laboratory instruments.

Summary

The use of the psychrometric chart and the relationship of psychrometric variables and their effect on perishable commodities and how they can be measured and used by packinghouse and commercial cooler manager were presented. A better understanding of psychrometrics will allow packinghouse operators and commercial cooler operators to improve post harvest cooling and storage conditions for fresh vegetables. A $500 investment in a simple, reliable, and accurate hand-held thermocouple thermometer and portable psychrometer and use of a psychrometric chart will allow the determination of all the psychrometric variables needed to properly control the ambient environment within prec coolers and cold storage rooms. Proper use of these tools will allow the managers to correct problems (such as high temperatures and low moisture levels) and maintain the quality and reduce the spoilage of their valuable perishable commodities.

Literature Cited


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TEMPERATURE CONDITIONING INHIBITS CHILLING INJURY IN SUMMER SQUASH (CUCURBITA PEPO) FRUIT

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Abstract. Effects of prestorage temperature conditioning on the development of chilling injury, ethylene evolution, and polyamine levels were compared in ‘Caserta’ (B+/B+) and the more chilling sensitive ‘Precocious Caserta’ (B/B) summer squash fruit. Fruit were either placed at 5°C immediately after harvest or temperature conditioned at 10°C for 2 days prior to transfer to 5°C. Fruit were transferred from 5°C to 20°C at 2 day intervals for a period of 12 days. At the time of transfer and 24 hours later, fruit were rated for chilling injury symptoms and ethylene evolution was determined. Samples of fruit peel were frozen and subsequently used for polyamine analysis.

Temperature conditioning reduced the development of chilling injury symptoms and suppressed chilling-induced ethylene evolution in both genotypes. The beneficial effect of conditioning, however, was greater in B+/B+ than in B/B. Significant differences in levels of the polyamines putrescine, spermidine, and spermine were detected between cultivars and conditioning. Spermine levels increased during storage more in B+/B+ than in B/B, and in both genotypes spermine levels were enhanced by conditioning. The greater resistance to chilling injury in B+/B+ than in B/B and in conditioned versus nonconditioned fruit may be related to the ability of the tissue to accumulate spermine.

Introduction

Summer squash (Cucurbita pepo L.) fruit develop chilling injury (CI) when stored at temperatures at or below about 5°C (Hardenburg et al., 1986). Symptoms of CI in summer squash include surface pitting, peel discoloration, and increased susceptibility to decay. Gene B conditions for precocious yellow fruit pigmentation in C. pepo and has been incorporated into a number of commercially important cultivars (Shiffriss, 1981). The presence of gene B increases the susceptibility of summer squash to CI (McCollum, 1990; Sherman et al., 1985); however, the physiological basis for this increase in chilling sensitivity is not known.

Prestorage temperature conditioning has been reported to increase resistance to CI in summer squash (Kramer and Wang, 1989a, b), watermelons (Picha, 1986), grapefruit (Hatton and Cabbage, 1982), and bell peppers (McColloch, 1962). Temperature conditioning involves holding fruit at a temperature slightly above the threshold for CI prior to storage at chilling temperature (Hatton, 1990).

Kramer and Wang (1989b) reported that temperature conditioning enhanced levels of spermine and spermidine in zucchini squash fruit, and that treatment of fruit with spermine prior to storage inhibited the development of CI. Differences in polyamine levels may be related to the differences in chilling sensitivity conferred by gene B.

The objectives of the present study were to determine if summer squash genotypes with and without gene B respond similarly to temperature conditioning, and if differences in chilling tolerance are related to polyamine levels.

Materials and Methods

Summer squash genotypes ‘Caserta’ (B+/B+) and the more chilling sensitive ‘Precocious Caserta’ (B/B) were grown at the Leesburg Agricultural Research and Education Center, Leesburg, Fla. during the spring of 1990. Fruit were harvested in the morning (prior to 1000 hr), and transported to the laboratory in Orlando (ca. 67 km). The fruit were rinsed in tap water, dipped in water containing 100 ppm chlorine and allowed to dry. The fruit were then either placed directly at 5°C (nonconditioned) or at 10°C for 2 days (conditioned), after which they were transferred to 5°C. Samples of 4 fruit were removed from 5°C storage at 2 day intervals and visually rated for CI on a scale of 0-4, with 0 = no visible CI; 1 = trace; 2 = slight; 3 = moderate; and 4 = severe CI. Fruit rated 3 or above were considered to be unmarketable. Twenty-four hours following transfer to 20°C, ethylene evolution was measured from 4 individual fruit as described previously (McCollum, 1989). At the time of transfer to 20°C, peel samples were removed from the fruit using a vegetable peeler and frozen in liquid nitrogen. The peel samples were stored at -80°C until used for polyamine analysis. Polyamines were extracted and analyzed following methods described previously (McDonald, 1989).

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