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# *Silage review:* Unique challenges of silages made in hot and cold regions[1]

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## ABSTRACT

Silage making can be conveniently divided into field, ensiling, storage, and feed-out phases. In all of these stages, controllable and uncontrollable components can affect silage quality. For instance, silages produced in hot or cold regions are strongly influenced by uncontrollable climate-related factors. In hot regions, crops for silage are influenced by (1) high temperatures negatively affecting corn yield (whole-crop and grain) and nutritive value, (2) butyric and alcoholic fermentations in warm-season grasses (*Panicum*, *Brachiaria*, and *Pennisetum* genera) and sugarcane, respectively, and (3) accelerated aerobic deterioration of silages. Ensiling expertise and economic factors that limit mechanization also impair silage production and utilization in hot environments. In cold regions, a short and cool growing season often limits the use of crops sensitive to cool temperature, such as corn. The fermentation triggered by epiphytic and inoculated microorganisms can also be functionally impaired at lower temperature. Although the use of silage inoculants has increased in Northern Europe, acid-based additives are still a good option in difficult weather conditions to ensure good fermentation quality, nutritive value, and high intake potential of silages. Acid-based additives have enhanced the quality of round bale silage, which has become a common method of forage preservation in Northern Europe. Although all abiotic factors can affect silage quality, the ambient temperature is a factor that influences all stages of silage making from production in the field to utilization at the feed bunk. This review identifies challenges and obstacles to producing silages under hot and cold conditions and discusses strategies for addressing these challenges.

**Key words:** silage problem, silage production, temperate crop, tropical crop

## INTRODUCTION

Silage making is an old agricultural practice that started more than 3,000 yr ago (Wilkinson et al., 2003). However, a rapid increase in the application of this technology occurred after the 1940s as a result of the mechanization of forage harvesting (Wilkinson et al., 2003). Silage making is well established in the temperate regions of North America and Europe but has only recently become popular and widespread in tropical regions (Wilkins and Wilkinson, 2015).

Production of high-quality silage is dependent on both controllable and uncontrollable factors. Silage management factors that are under the control of the farmer are forage species and agricultural background, stage of maturity or moisture concentration at harvest, harvesting and ensiling methods, type of storage structure, use of silage additives, feed-out methods, feed bunk management, and diet formulation (Mahanna and Chase, 2003). Uncontrollable climate-related factors that are common or specific to warm or cold regions can adversely affect silage production and utilization and can influence some of the factors listed above, such as moisture concentration at harvest. The objective of this article is to identify challenges and obstacles to producing silages under hot and cold conditions and to discuss strategies for addressing these challenges.

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## SILAGE MAKING IN HOT AREAS

### *Effects of High Temperature on the Yield and Attributes of Crops and Silages*

The concentration and digestibility of NDF are by far the most important variables related to forage nutritive value. However, in ensiled forages, the nutritive value is further affected by the fermentation pattern (extent and profile), which in turn can influence DMI (Huhtanen et al., 2007). The prevailing climate can exert considerable effects on the DM yield and quality of silages, and in some instances these effects may surpass the effect of maturity at harvest on the ensiling process.

***Corn and Sorghum.*** Relatively few studies have focused on the effects of temperature on the yield of whole corn plants. For instance, Struik (1983) reported that high temperatures accelerated kernel development and leaf senescence, reducing kernel viability and final plant yield. Effects of temperature alone on crop yields are typically determined via modeling to avoid the confounding effects of several other factors such as the location, soil type, nutrient status, management, and other climatic attributes. Most of the existing research has focused on corn kernel yields rather than yields of the whole plant. Muchow et al. (1990) used modeling to demonstrate the inverse relationship between increasing temperatures and corn grain yield in the following cities: Gainesville, Florida; Katherine, Australia; Quincy, Florida; Champaign, Illinois; and Grand Junction, Colorado. They highlighted the importance of the length of the grain-filling period in determining the yield because the DM in the grain is largely accumulated after flowering and is typically inversely related to increasing temperature. Schlenker and Roberts (2006) reported that corn yields decreased in a nonlinear manner with temperatures above 25°C, but even short periods above 30°C caused considerable yield losses. Likewise, based on climate and yield data spanning most US counties from 1950 to 2005, Schlenker and Roberts (2009) reported that the yield of corn grain gradually increased up to 29°C, but temperatures above this threshold markedly reduced yields. They noted that the slope of the decline above the optimum value of 29°C is much steeper than the incline below it. In addition, Bassu et al. (2014) evaluated 23 models for corn growth at 4 locations representing a wide range of corn production conditions around the world (Ames, Iowa; Lusignan, France; Morogoro, Tanzania; and Verde, Brazil). Several models indicated that temperature increases above 30°C reduced grain yield by 0.5 t/ha per Celsius degree.

Corn silage is the most energy dense forage source used in dairy cow diets in tropical environments (Bernardes and Rêgo, 2014; De Oliveira et al., 2017). However, corn silage from hot or tropical regions is usually poorer in quality compared with corn silage produced in cool or temperate climates. Adesogan (2010) reviewed the chemical composition of 3,070 corn silage samples from Florida and New York analyzed at the Dairy One Forage Laboratory (Ithaca, NY) over a 5-yr period (2004–2009). Florida corn silages consistently had lower concentrations of starch and greater concentrations of acid detergent-insoluble CP (**ADICP**), NDF, ADF, and lignin. The greater cell wall and ADICP concentrations in the Florida silages may be attributable to the effects of higher temperatures on cell wall deposition, although this cannot be verified because the data were not from a controlled experiment. Nevertheless, several authors have reported that high temperatures increase fiber or lignin deposition (Wilson et al., 1991; Moore and Jung, 2001). This is partly because higher temperatures increase the rate of plant development (Buxton, 1996) and the activity of lignin synthetic enzymes (Buxton and Fales, 1994). These responses increase the partitioning of DM to more lignified tissues, such as the shoots (Hardacre and Turnbull, 1986; Cone and Engels, 1990; Moore and Jung, 2001). The higher ADICP concentration in the Florida versus New York silages sampled by Adesogan (2010) is consistent with the effects of higher temperatures in the study of Garcia et al. (1989). Likewise, Kim and Adesogan (2006) reported that a higher ensiling temperature (40 vs. 20°C) increased the concentration of ADICP or heat-damaged proteins in corn silage. Reactions between sugars and amino groups form the ADICP through the Maillard reaction, which occurs at >40°C in silages (Muck et al., 2003). The rate of the reaction also increases exponentially with temperature (Goering et al., 1973). Heat-damaged proteins formed in the Maillard reaction are usually indigestible in vivo; therefore, elevated temperatures can reduce the feed value of protein in corn silage.

Logically, lower grain yields at higher temperatures also result in lower starch concentration in corn silage due to the influence of temperature on starch synthase, the enzyme controlling starch synthesis in the grain. Keeling et al. (1994) reported that temperatures above 30°C irreversibly inactivate starch synthase, precluding the deposition of starch in the kernel. However, a study conducted in Brazil found that corn silage produced on intensive dairy farms located in the south and southeast had satisfactory starch concentration (De Oliveira et al., 2017), as shown in Figure 1.

Corn silage digestibility is usually decreased at high temperatures due to the reduction in starch concentration and increase in lignin and fiber deposition in the plant. Cone and Engels (1990) reported that corn grown at higher temperatures (12 h at 30°C and 12 h