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Photoperiod sensitivity of local millet and sorghum varieties in West Africa

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A B S T R A C T

Photoperiod has a strong impact on the development of local millet and sorghum varieties which are two of the most important staple food crops for millions of people in West Africa. Therefore, a better understanding of the response to photoperiod is needed in order to improve production and ultimately increase yield. Several studies have demonstrated the importance of the adaptive capability of local varieties, especially in coping with environmental stress conditions. The objective of this study was to determine the photoperiod sensitivity (PS) characteristics of the most common local varieties of millet and sorghum in Burkina Faso, West Africa. Planting date experiments consisting of 5 or 6 planting dates with complementary irrigation and fertilizer to avoid water and nitrogen stress effect on phenology were conducted at the experiment station of Di in northwestern Burkina Faso during the rainy seasons of 2003, 2004, 2006 and 2007. The study included 7 millet and 11 sorghum varieties from the three main agroecological zones in Burkina Faso to determine their sensitivity to photoperiod. In addition to the various key phenological parameters, panicle initiation date was measured in 2007. Therefore, thermal time from emergence to PI and photoperiod at PI could be experimentally determined. After evaluation of the relation between the PI stage and the other stages that could easily be observed, thermal time from emergence to flag leaf expansion was used to determine the date of panicle initiation (PI) as well as the photoperiod at PI for the experiments conducted from 2003 to 2006. Then, a graphical analysis was conducted to define the critical threshold photoperiod and photoperiod sensitivity for each variety. For both millet and sorghum, the photoperiod sensitivity ranged from 142 to 6184 growing degree days (GDD h^{-1}) per hour of photoperiod extension. The critical photoperiod (Pc) ranged from a daylength of 13.00 to 13.35 h. Although these experiments were only conducted at one location, this study showed that photoperiod response is not only related to latitude, but depends also on the capability of lowlands to maintain soil moisture. There was a positive correlation between the critical photoperiod (Pc) and the latitude of origin of the local varieties and a negative correlation between photoperiod sensitivity and the latitude of origin. Further work will include the implementation of these results in crop simulation models for yield forecasting and the determination of crop management alternatives for millet and sorghum in West Africa

1. Introduction

In Burkina Faso, a landlocked country of West Africa, the rainy season ranges from 2 to 3 months (July to September) in the north, from 3 to 4 months (June to September) in the central region, and from 5 to 6 months (May to October) in the south. Depending on the variability of the rainy season, millet [*Pennisetum glaucum* L.)], sorghum [*Sorghum bicolor* (L.) Moench], maize [*Zea mays* L.], and rice [*Oriza sativa* L.] are the most important cereal crops that are grown, similar to other countries in West Africa. While millet production dominates in the northern part of Burkina Faso, millet and sorghum are both important in the central part, and sorghum and maize dominate in the south. Rice and maize are common in the lowlands of the south, where irrigation is practiced [1]. Millet and sorghum are normally intercropped with cowpea [*Vigna unguiculata* (L.) Walp] and/or groundnut [*Arachis hypogea* (L.)]. The staple

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foods in Burkina Faso are millet and sorghum grain, while their stover is used for livestock feed, for construction, and for various other uses [2,3].

Depending on the planting date, local varieties of millet and sorghum that are sensitive to photoperiod can produce canopies that are between 1.5 and 5 m tall and that have 12 to 41 leaves on the main stem [4]. They are characterized by a very low yield, with tall canopies, and their growing cycle varies according to the climatic zone and the planting date. The low yield is mostly due to the short rainy season with dry spells, a high potential evapotranspiration rate, low soil fertility, and low levels of agrotechnology. One of the most adaptive characteristics of millet and sorghum to West African conditions is their sensitivity to photoperiod, which decreases from the south (low latitude) to the north (high latitude). This photoperiod sensitivity has been observed for many other agronomic crops, including flax, kenaf, oats, rape, rice, rye, soybean and wheat [5–8].

Photoperiod delays the genetic tendency to flower by forcing the plant to wait for a specific signal [9]. Millet and sorghum are short-day photoperiod sensitive crops. Progress towards flowering is accelerated when the daylength decreases below the critical photoperiod. In West Africa, favorable conditions for millet and sorghum production usually extend from May to November. Thus, most of the development occurs under a decreasing daylength, which explains why the duration of their cycle shortens when sowing is delayed during the rainy season in West Africa. The sensitivity to photoperiod is a singular trait for adaptation to environmental constraints. In the Sudano-Sahelian zone, it allows the crop to consolidate flowering towards the end of the rainy season for a wide range of planting dates [2,3,9,10].

Homeostasis refers to the heading date of local varieties occurring at the same period at the end of the rainy season, even if there are large differences among their planting dates. In Nigeria, where a local sorghum variety from Samaru was planted from 9 May to 15 July (range 67 days), all plants headed within the 11-day period between 6 and 17 October [12–15]. The heading date of local varieties in Mali occurs, on average, about 17 days before the end of the rainy season at their respective locations [16]. The same has been reported for millet in Senegal and Mali [3]. These heading dates are, therefore, a compromise between (i) escaping diseases (head moulds) and insects prevalent in the high humidity conditions during the rains and (ii) avoiding drought during seed filling [10,12]. Andrews [13] and Kassam and Andrews [14] concluded that the mechanism of homeostasis was probably determined by photoperiod, since temperature did not vary greatly between sowing dates. Photoperiod affects crop development and offers opportunities and challenges for agriculture, such as breeding for varieties that flower at the most appropriate time for a given environment [17]. Vaksmann *et al.* [10] reported that sensitivity to photoperiod remains necessary, even for improved varieties, in the present grain production systems in the African savannas and the Sahel to be able to optimize natural resource use and minimize the risk of adverse climatic effects.

Several studies have been conducted to determine the photoperiod response of sorghum for either field conditions [14,18–21] or controlled environments [22–24]. Major [5] identified three genetic components to describe the varietal response to photoperiod: (i) the Basic Vegetative Phase (BVP), defined as the minimum thermal time required for panicle initiation under optimum daylength; (ii) the Minimum/Maximum Optimal Photoperiod (MOP), defined as the critical photoperiod (Pc) beyond which the vegetative period is influenced by changes in daylength; and (iii) the Photoperiod Sensitivity Slope (PSS), which, from the MOP, expresses the linear increase of time to flowering for individual varieties. Thus, for short-day plants, under optimum daylength conditions, the duration of the Photoperiod Inductive Phase (PIP) is assumed to be 0 degree-days, and no delay in flowering occurs.

Considerable progress has been made in understanding how the duration from planting to panicle initiation (PI), anthesis (AN) and maturity (M) in sorghum is modulated by photoperiod and temperature. In general, the duration for each growth stage is related to thermal time. The duration to PI comprises a juvenile or pre-inductive phase followed by an inductive photoperiod-sensitive phase, and the rate of progress can be quantified by linear responses to mean temperature and photoperiod [11,22,25]. Results have shown that the sensitivity of sorghum to photoperiod ranges from 0 to more than 40.5 days per one hour increase in photoperiod, with a critical or threshold photoperiod that varies between 12 and 14 hours [26]. In Nigeria, Craufurd and Qi [12] found that the PSS of a local variety was 2115 GDD h^{-1} with a critical photoperiod of 12.9 h. The values found by Chantereau *et al.* [20] ranged from 1546 to 3971 GDD h^{-1} and were higher than the 1160 GDD h^{-1} presented by Folliard *et al.* [27]. The values reported by Alagarswamy et al. [23] for improved varieties were very low compared to the high photoperiod sensitivity varieties of West Africa.

One of the least destructive methods to determine photoperiod sensitivity is based on the observation of crop development for different planting dates in the field for a given natural environment, because it does not use artificial lights to extend the daylength or artificial growth chamber conditions. PSS for each cultivar should be obtained through a simple planting date experiment during the normal growing season. Understanding the impact of photoperiod on local millet and sorghum varieties for conditions in West Africa could help improve crop management under severe conditions of growth and development, and contribute to decision making for food security. Primary results have shown that the Photoperiod Sensitivity Slope has a very large range among varieties. Thus, to better understand and to improve millet and sorghum production for a given environment, it is important to determine the response of the main local varieties to photoperiod.

Most of the previous studies have focused on the impact of latitude or daylength on the photoperiod sensitivity of millet and sorghum. However, the long-term adaptation of a variety can include both photoperiod and soil moisture conditions in the lowlands that link with the farmers' production systems. During field experiments conducted in three agroclimatic zones of Burkina Faso, we encountered some difficulties in simulating millet and sorghum production using the available photoperiod coefficients, as they did not simulate the cycle of local varieties grown by producers very well. The objective of this study, therefore, was to determine the response to photoperiod of different millet and sorghum varieties that are commonly grown in three agroecological zones of Burkina Faso, West Africa, and then contribute to databases that can be used in crop simulation models.

2. Materials and Methods

2.1. Experimental site

The experiments were conducted at the Di experiment station, located 42 km northwest of Tougan, Burkina Faso (lat. 13.12° N, long. 3.13° W; 300 m above sea level). The location is characterized by an average annual rainfall of 640 mm, while the rainy season spans from April to October. The field used for the experiment had been cropped continuously since 1999 with a rotation of onion during the dry season and maize or rice during the rainy season. The soil of the experimental area corresponds to a vertic loamy soil, with a pH of 7.5 at a depth of 15 cm. The experiments were conducted at the same site during the rainy seasons of 2003, 2004, 2006 and 2007.