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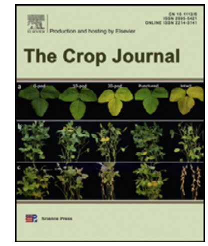

Heterosis in locally adapted sorghum genotypes and potential of hybrids for increased productivity in contrasting environments in Ethiopia

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ABSTRACT

Increased productivity in sorghum has been achieved in the developed world using hybrids. Despite their yield advantage, introduced hybrids have not been adopted in Ethiopia due to the lack of adaptive traits, their short plant stature and small grain size. This study was conducted to investigate hybrid performance and the magnitude of heterosis of locally adapted genotypes in addition to introduced hybrids in three contrasting environments in Ethiopia. In total, 139 hybrids, derived from introduced seed parents crossed with locally adapted genotypes and introduced R lines, were evaluated. Overall, the hybrids matured earlier than the adapted parents, but had higher grain yield, plant height, grain number and grain weight in all environments. The lowland adapted hybrids displayed a mean better parent heterosis (BPH) of 19%, equating to 1160 kg ha^{-1} and a 29% mean increase in grain yield, in addition to increased plant height and grain weight, in comparison to the hybrids derived from the introduced R lines. The mean BPH for grain yield for the highland adapted hybrids was 16% in the highland and 52% in the intermediate environment equating to 698 kg ha^{-1} and 2031 kg ha^{-1}, respectively, in addition to increased grain weight. The magnitude of heterosis observed for each hybrid group was related to the genetic distance between the parental lines. The majority of hybrids also showed superiority over the standard check varieties. In general, hybrids from locally adapted genotypes were superior in grain yield, plant height and grain weight compared to the high parents and introduced hybrids indicating the potential for hybrids to increase productivity while addressing farmers' required traits.

Abbreviations: BLUP, Best linear unbiased predictor; BPH, best parent heterosis; DTF, days to flowering; GN, grain number head^{-1}; GW, hundred grain weight; GY, grain yield; HLA, highland adapted hybrids; IRL, introduced R line hybrids; LLA, lowland adapted hybrids; PTH, plant height.

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1. Introduction

Sorghum (*Sorghum bicolor* L. Moench) is a C_4 cereal crop domesticated in Africa; it is adapted to water stress, low soil fertility and high temperature conditions. *Sorghum* is a staple crop for more than 500 million people in 30 sub-Saharan African and Asian countries [1], while it is primarily grown as feed grain in the developed world.

In Ethiopia, which is the sixth largest sorghum producing country in the world, sorghum contributes 17% of the total annual cereal grain production [1,2]. It is grown in highly diverse environments, which can be broadly classified into three major agro-ecologies; highland areas >1900 m, intermediate areas between 1600 and 1900 m and lowlands areas <1600 m above sea level, characterized by distinct edaphic and climatic conditions [3]. Sorghum productivity is constrained by different biotic and abiotic factors mainly drought and *Striga* (a parasitic weed) in the lowland and biotic stress in the highland and intermediate environments.

Sorghum is predominantly grown by smallholder farmers in Ethiopia. The highest proportion (74%) of the grain produced is consumed at the household level, with the remainder being used for sale and seed purposes [2]. The grain is used for preparation of different local staple food products such as leavened bread (*injera*), porridge and local beverages that require specific grain quality characters. Grain size and color are important traits to farmers in selecting varieties [4]. Increased grain size with corneous endosperm is preferred and larger seeded varieties fetch a better price, possibly due to higher milling yields and higher water absorbance [5]. The stover, which has uses for animal feed, fuel and construction of fences, is often valued as highly as grain yield, hence taller varieties are highly preferred by farmers [4,6]. However, the improved varieties released in Ethiopia to date have had very low adoption rates. Lack of farmers preferred traits in these released varieties is the major impediment to their wider adoption [4,7]. The majority (85%) of the improved varieties released for use in the lowland and intermediate environments were developed using lines introduced from outside of Ethiopia; these are characterized by short plant stature, early maturity and lower grain size [4,8]. All varieties released for the highland environment to date have been pure lines selected from highland landrace collections; however, these released improved varieties only have limited yield advantage compared to the farmers' selected varieties or landraces [4].

The demand for improved varieties with both higher grain yield and farmer's preferred traits, primarily grain size and plant height, is increasing due to the rapidly growing human population and changing standard of living. Hybrid technology could have the potential to increase productivity while retaining high biomass and large grain size. Sorghum hybrids have been grown by farmers in developed countries since the late 1950s after the discovery of a viable cytoplasmic male sterility system, allowing cost-effective hybrid production, and are increasingly being adopted in the developing world [1]. In sorghum superiority of the F_1, or hybrid vigour, can result in a 30–40% increase in grain yield, depending on the environment and the genotypes used [9,10]. In addition to increasing yield, sorghum hybrid vigor has also been demonstrated to have increased yield stability over inbred lines, particularly in stressed environments [10,11].

Efficient and successful hybrid breeding requires the development of complementary parental pools [12]. In a mature hybrid crop breeding system such as maize, this has involved the development of genetically divergent parental pools that combine consistently to produce high yielding hybrids. While such heterotic pools exist for sorghum, they have been developed for production environments in temperate and subtropical zones where advanced, highly mechanized agricultural techniques are used, such as in the USA and Australia [13–15].

A number of studies have investigated the utility of developing hybrids in sorghum for adoption in the semi-arid tropics of Africa [16,17] and in Ethiopia [4,18], based on combinations from introduced restorer (R) and male sterile (A) lines. These studies consistently identified hybrids that produced more grain yield than the parental lines and local check varieties; however, the hybrids lacked the adaptive traits for diverse local environments, were short in plant stature and had lower grain size. The development of heterotic pools adapted to a particular environment is one solution to overcome the challenges of both local adaptation and local farmers' end use requirements [19–21]. However such a strategy is complicated by the constraint that the cytoplasmic male sterile system imposes on developing new sorghum female parental lines [22]. In a recent study the genetic patterns of differentiation of locally adapted Ethiopian genotypes, in comparison to the introduced R and B lines, were identified using genome-wide SNP markers [23]. The current study focused on investigating the effectiveness of developing high yielding hybrids that also address the adaptation issue and multiple trait demands of farmers using selected locally adapted genotypes in combination with existing introduced seed parents and assessing whether there were correlations between parental genetic distance, using genome-wide SNP data generated previously, and performance. The specific aims of the current study were to 1) assess the performance of hybrids derived from locally adapted genotypes and introduced R lines in combination with introduced A-lines in contrasting environments in Ethiopia; and 2) assess the magnitude of heterosis within and between locally adapted and non-adapted genotypes.

2. Material and methods

2.1. Genetic materials

A total of 26 sorghum inbred lines consisting of 18 pollinator (R) and eight cytoplasmic male sterile (CMS) seed parental (A) lines were used to develop 139 F_1 hybrids using an unbalanced design II mating scheme (Table S1). These lines were selected from distinct groups identified among a diverse set of 184 Ethiopian genotypes selected from the Ethiopian working collection representing the highland, intermediate and lowland agro-ecologies, and introduced inbreds, differentiated using 11,788 genome-wide SNPs generated following integrated DArT and genotyping-by-sequencing (GBS) [23]. The genotyping method involved removal of repetitive sequences