Breeding for Forage Hybrid Sorghum [*Sorghum bicolor* (L.) Moench] in the Sudan Using Local Stocks as Males and Introduced Genetic Stocks as Females

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Dedication ……….

To the memory of my mother : Safi'ya bit Babikir, and grandmothers : Fatima and Asha……….

Abstract

The study was conducted in Khartoum State for two years (2002-2003) and at two locations (Shambat and Islang). The objective was to investigate the possibility of local development of forage hybrid sorghum [*Sorghum bicolor* (L.) Moench] using 4 local stocks as pollinators and 7 introduced genetic stocks sterilized in A3 cytoplasm as females. The commercial hybrid ‘Panar 888’ was used as standard check. The material was evaluated for agronomic performance and the proximate analysis for some forage quality traits was undertaken. Combining ability study was performed using line x tester analysis and the magnitude of average heterosis, heterobeltiosis and standard heterosis were investigated.

Highly significant differences were detected among entries for all characters studied. Partitioning of the entry source of variation revealed significant differences among the various subgroups of entries for all characters. The interaction of entry and its various subgroups with location, unlike that with years, was insignificant for all characters. The second order interactions with hybrids and their parents were insignificant for all characters; however, the comparatively low mean squares of hybrids, pointed to their relative consistency over environments compared to parents.

Many hybrids excelled the parental lines in forage yield and some of the yield-related traits. The hybrids : E-35-1 x S. 70, E-35-1 x S. 186, E-35-1 x Garawi and Dale x S.70 significantly out-yielded the commercial hybrid ‘Panar 888’ and the parental lines derived from the local cultivar ‘Abu Sab’in’. The increase in yield attained by these hybrids was attributed to the increase in stem diameter and plant height. The commercial hybrid excelled the experimental hybrids in leaf to stem ratio, tillering and regrowth.

The proximate analysis for neutral detergent fiber, crude fiber and Ash indicated that the overall nutritive value of hybrids was better than their parents. Crude protein percentages

of hybrids averaged slightly lower compared to their parents. However, this was suggested to be mitigated by the improved intake potential of hybrids.

The heterosis study revealed that significant gains in forage yield over mid-parent, better parents and the commercial hybrid ‘Panar 888’ were exhibited by some hybrids indicating that the superiority over the existing maxima in forage yield has been demonstrated. Hybrids with the best heterotic effects for forage yield and at the same time maintaining good performance for this character were those involving the line E-35-1 with the testers : S. 70, S. 186 and Garawi, plus Dale x S.70, Hastings x S. 70 and Sugar Drip x Ankolib. Of these, the hybrids Dale x S.70 and Hastings x S. 70 displayed the best compromise between forage yield, earliness and quality traits. In contrast, the hybrids involving E-35-1 showed undesirable heterosis for earliness and some quality traits. Generally, the means of average heterosis and heterobeltiosis indicated that the general trend for heterotic effects were towards increased forage yield, plant height, stem thickness, tillering, regrowth and reduced leaf to stem ratio.

Significant general (GCA) and specific (SCA) combining ability effects in the desirable direction were detected for most agronomic and quality traits. The best general combiners for forage yield were E-35-1 and Dale from lines and S. 70 (selection from Abu Sab’in) from testers. Dale was given the top priority as it maintains desirable GCA effects for many other characters including quality traits. E-35-1, although better than Dale in GCA for forage yield, it turned out to be the poorest general combiner for earliness in flowering, a character highly needed under the prevailing forage production system in the Sudan. It was concluded that economic evaluation may validate the utility of the of E-35-1 hybrids, especially in the highly specialized animal-products sector, where lateness in flowering is not a major problem. Blue Ribbon from lines and Garawi (traditional Sudan grass cultivar) from testers were promising general combiners for earliness. Garawi was also a promising general combiner for leaf to stem ratio, regrowth and tillering, but was the poorest for forage yield. Since Garawi is a highly heterogeneous cultivar, it was suggested that its GCA for forage yield might be improved by selection. Ankolib from testers was also a good general combiner for leaf to stem ratio.

For quality traits, Dale from lines and S. 70 from testers were the best general combiners for neutral detergent fiber, followed by the line Hastings and the tester S. 186. The line Hastings was also the best general combiner for crude protein. Blue Ribbon and Sugar Drip from lines and Ankolib from testers were the best general combiners for Ash.

The best SCA effects for forage yield were obtained by Sugar Drip x Ankolib followed by Blue Ribbon x Ankolib. Other hybrids with significant SCA effects for forage yield include : E-35-1 x Garawi, Dale x S.70, Hastings x S.70 and E.35-1 x S.186. All these hybrids were among the best yielders, but their yield ranks were not necessarily similar to those of their SCA effects. For earliness in flowering, the best specific effects were shown by E-35-1 x Ankolib, Dale x Ankolib, and Hastings x Garawi. For leaf to stem ratio, the best specific effects were shown by N 100 x Ankolib followed by E-35-1 x Ankolib**.** The best SCA effects for regrowth were shown by Sugar Drip x S.186, Dale x Garawi and N 100 x S.70.

With few exceptions, both general and specific effects were important in the expression of all characters, with general effects being more important than the specific ones. Consequently, both additive and non-additive gene actions were important in the expression of most characters with the preponderance of additive gene actions for days to flower, forage yield, stem diameter, leaf to stem ratio and non-additive actions for plant height and regrowth. The exception being number of tillers per plant which appears to be mainly under the control of additive effects. General effects were more stable over years than specific effects. Interactions of genetic effects with years were more pronounced than those with locations. It was postulated that, testing over years at one location with increased number of replications, might be of value for combining ability evaluation.

The contributions of either lines or testers to the total variance were higher than those of line x tester for all characters other than plant height and regrowth. The variability observed among both parental groups was in most cases, not coinciding with their contribution to the total variance. It was suggested that high variability among a parental group did not necessarily imply high contribution of that group to the total variance of the crosses.

Selection in early generations might be effective in improving characters predominately controlled by additive genes like number of tillers per plant and days to flower. For characters like forage yield, leaf to stem ratio and regrowth in which both additive and non-additive gene actions were important, it was pointed that the A3 sterility source will preclude the employment of reciprocal recurrent selection in their improvement. Alternatively, heterosis breeding was recommended for forage yield improvement, but for leaf to stem ratio and regrowth, it was suggested that heterosis breeding must be preceded by a selection program based on more genetically diverse material with increased number of lines.

Since the exotic material may transfer traits not adapted to the local production system, the choice for local x local hybrids was highly recommended. Male-sterilizing the local stocks in A3 cytoplasm was therefore suggested to benefit from the wide range of variability known to exist in sorghum in the Sudan. Preliminary selection within local stocks was suggested to eliminate undesirable traits or to include some easily inherited desirable traits like juiciness.

تربية هجن أعلاف الذرة الرفيعة [*Sorghum bicolor* (L.) Moench] السودان
باستعمال ذكور من الأصول ا لية و إناث ذات أصول وراثية مستجلبة

ا لاصة

أجريت الدراسة ولاية ا رطوم موقع (بات و اسلانج) و دة عامي (2002 و 2003) بـ هدف دراسة إمكانية تطوير هجن أعلاف الذرة الرفيعة ليا باستعمال أربعة ذكور لية كأصناف اختباريه و سبعة إناث (خطوط) مستجلبة ذات عقم سيتوبلازمي من النوع A3 . أستعمل ا جـ التجاري بانار 888 كشاهد وذجي. تقييم ا جن لعدد من الصفات ا قلية و النوعية. كما دراسة قوة ا جـ و أستعمل ليل ا ط x الصنف الإختباري لدراسة قدرة التوافق العام.

أوضحت الدراسة وجود فروق معنوية عالية بـ ا عاملات و ا موعات ا كونة ا ميع الصفات ا قلية و النوعية. التفاعل التباد للمعاملات و ا موعات ا كونة ا مع ا واقع كان غ معنوي لكل الصفات بينما كان معنوياً مع السنـ عظم الصفات. التفاعل التباد من الدرجة الثانية للمعاملات و موعا ا كان غ معنوياً لكل الصفات بيد أن الا فاض النسـ لتباين ا جن يدل علي إ ا اكثر استقراراً من الآباء ء السنـ و ا واقع.

كثـ من ا جن تفوقت علي الأبوين الإنتاجية و بعض الصفات ا تعلقة ا. ا جن الا تفوقت معنوياً الإنتاجية علي ا جـ التجاري بانار888 و الآباء ا نتخبة من الصنف التقليدي أبو سبعـ هي : E-35-1 x S. 70 ، E-35-1 x S. 186 ، E-35-1 x Garawi و Dale x S. 70. عزيت الزيادة إنتاجية ا جن للزيادة ك الساق و طول النبات. ا جـ التجاري بانار888 تفوق علي ا جن التجريبية نسبة الأوراق للساق ، إنتاج ا لف و إعادة النمو.

التحليل التقريـ (Proximate Analysis) للألياف الذائبة أوساط متعادلة(neutral detergent fiber) ، الألياف ا ام (crude fiber)، و الرماد (Ash) دل علي أن القيمة الغذائية الكلية للهجن أعلي من تلك ا اصة بالآباء. متوسط النسبة ا ئوية للا وتـ ا ام (crude protein) للهجن أقل قدار بسيط مقارنة بالآباء ، بيد أن تفوق ا جن إمكانية العلف ا أكول ستعمل علي تسوية هذا الفرق.

أوضحت دراسة قوة ا جـ أن عدداً من ا جن اكتسبت زيادة معنوية إنتاجية العلف بالنسبة توسط الأبوين ، أفضل الأبوين و ا جـ التجاري بانار 888 ا يدل علي اوز السقف الراهن لإنتاجية العلف و بالتا إيضاح جدوى استعمال قوة ا جـ كطريقة لتربية أعلاف الذرة. ا جن الا أظهرت أكـ قدر من قوة ا جـ و نفس الوقت احتفظت بإنتاجيتها العالية تشمل تلك الا يدخل فيها ا ط E-35-1 مع الأصناف الاختبارية S. 70 ، S. 186ـ ، ا راوي بالإضافة إ Dale x S. 70 ، Hastings x S. 70 و Sugar Drip x Ankolib . من بـ هذه ا جن ثل ا جينان Dale x S.70 و Hastings x S.70 التوافق الأمثل بـ إنتاجية العلف و صفة التبكـ الإزهار و القيمة الغذائية. و ا قابل فان ا جن ا توية علي ا ط E-35-1 أبدت قوة هجـ غ مرغوب فيها بالنسبة للإزهار ا بكر و بعض صفات القيمة الغذائية.

بصفة عامة ثلت قوة ا جـ توسط الأبوين و أفضل الأبوين الا اه و زيادة إنتاجية العلف ، طول النبات ، ك الساق ، إنتاج ا لف ، إعادة النمو و نقص نسبة الأوراق للساق.

أوضحت الدراسة أن هناك تأث أ معنوياً الا اه ا رغوب لقدرة التوافق العام و ا اص معظم الصفات ا قلية و النوعية. أحسن الآباء قدرة التوافق العام لإنتاجية العلف هي E-35-1 و Dale من ا طوط بالإضافة إ الصنف الاختباري S. 70 (سلالة منتخبة من أبو سبع). أعت ا ط Dale أفضلها يعاً لأنه تلك أيضاً قدرات توافق عامة مرغوبة لعدد من الصفات ا قلية و النوعية. ا ط E-35-1 بالرغم من تفوقه علي Dale قدرة التوافق العام للإنتاجية إلا أنه أقل ا طوط قدرةً علي التوافق العام بالنسبة للتبكر الإزهار وهي صفة هامة ت نظام إنتاج الأعلاف السائد في السودان. أقترح أن التقييم الاقتصادي ر ا يثبت جدوى الاستفادة من هجن هذا ا ط خاصة مشاريع الإنتاج ا يوا ا تخصصة حيث التأخ الإزهار لا يشكل مشكلة أساسية. بالنسبة للصفات ا تعلقة بالإنتاجية، أوضحت الدراسة أن ا ط Blue Ribbon و الصنف الإختباري ا راوي ما قدرة توافق عامة جيدة للتبكر الإزهار. أبدت ا راوي أيضاً قدرة توافق عامة جيدة لنسبة الأوراق للساق ، إنتاج ا لف و إعادة النمو ولكنها أقل الأصناف الاختبارية قدرة التوافق العام للإنتاجية. أقترح أنه نظراً لك الاختلافات داخل ا راوي، كن س قدر ا العامة للتوافق عن طريق الانتحاب. الصنف الإختباري عنكوليب أبدي قدرة جيدة للتوافق العام لنسبة الأوراق للساق.

بالنسبة للصفات النوعية ، أبدى ا ط Dale و الصنف الإختباري S. 70 أحسن القدرات للتوافق العام للألياف الذائبة أوساط متعادلة (neutral detergent fiber) يليهما ا ط Hastings و الصنف الإختباري S. 186 . يعت ا ط Hastings أيضاً الأحسن قدرة التوافق العام للنسبة ا ئوية للا وت ا ام. ا طان Blue Ribbon و Sugar Drip و الصنف الإختباري عنكوليب يعت ان الأحسن قدرة التوافق العام للنسبة ا ئوية للرماد. أحسن ا جن قدرة التوافق ا اص للإنتاجية هو Sugar Drip x Ankolib يليه ذلك Blue Ribbon x Ankolib . ا جن الأخرى ذات القدرات العالية للتوافق ا اص الإنتاجية هي E-35-1 x Garawi ، Dale x S.70 ، Hastings x S.70 و E-35-1 x S.186. كل هذه ا جن تعت من ب الأحسن إنتاجية العلف ولكن ترتيبها من حيث الإنتاجية ليس بالضرورة أن يتفق مع ترتيبها من حيث قدر ا ا اصة للتوافق. بالنسبة للإزهار ا بكر أبدت ا جن E-35-1 x Ankolib ، Dale x Ankolib و Hastings x Garawi أحسن القدرات للتوافق ا اص. ا ج N 100 x Ankolib أبدي أحسن قدرة للتوافق ا اص لنسبة الأوراق للساق يليه E-35-1 x Ankolib . أحسن ا جن قدرة التوافق ا اص بالنسبة لإعادة النمو هي Sugar Drip x S. 186 ، Dale x Garawi و N 100 x S.70 .

أوضحت الدراسة ، باستثناء عدد ا لف النبات ، أ ية كل من قدرة التوافق العام و ا اص، التحكم الصفات قيد الدراسة مع أ يه أكثر لتأث ات التوافق العام لكل الصفات عدا صف طول النبات و إعادة النمو. عليه فان كل من الفعل ا ي الإضا وغ الإضا يتحكمان تلك الصفات مع

سيادة الفعل ا يـ الإضا علي تأريخ الإزهار ، ك الساق ، إنتاجية العلف ونسبة الأوراق للساق و سيادة الفعل ا يـ غ الإضا علي طول النبات و إعادة النمو.بالنسبة لإنتاج ا لف فقد وجد أ ا ت سيطرة الفعل ا يـ الإضا بشكل أساسي. التأث ات الوراثية للتوافق العام كانت أكثر ثباتاً ع السن مقارنة بالتأث ات ا اصة. تفاعل التأث ات الوراثية مع السن كان أكثر وضوحاً مقارنة بتفاعلها مع ا واقع. أفترض أن الاختبار ع السن موقع واحد مع زيادة عدد ا كررات ر ا كان ذا فائدة لدراسة القدرة علي التوافق. مسا ة أي من ا طوط و الأصناف الاختبارية التباين الكلي للهجن كانت أك من مسا ة ا ط x الصنف الاختباري لكل الصفات عدا طول النبات و إعادة النمو. الاختلافات ا شاهدة داخل ا موعات الأبوية لا تنسجم مع مسا تهما التباين الكلي ا يش إ أن زيادة الاختلافات موعة أبوية ليس بالضرورة أن يع زيادة مسا ة هذه ا موعة التباين الكلي. أقترح أن الانتخاب الأجيال ا بكرة سيكون فاعلاً سـ الصفات الأكثر تأثراً بالفعل ا يـ الإضا مثل عدد الأيام للإزهار ، و إنتاج ا لف. بالنسبة للصفات مثل إنتاجية العلف ، نسبة الساق للأوراق و إعادة النمو ا يتحكم فيها الفعل ا يـ الإضا و غ الإضا ت الإشارة إ أن العقم السيتوبلازمي من النوع A3 سيعوق الاستفادة من طريقة الانتخاب ا تكرر التباد لتحسـ هذه الصفات. و بدلاً عن ذلك ، اقترح الاستفادة من قوة ا جـ لتحسـ الإنتاجية ولكن بالنسبة لبقية الصفات ب أن يسبق ذلك برنامج انتخاب مبـ علي قاعدة وراثية أكثر تنوعاً و ذات أعداد أك من ا طوط. و ا أن ا واد الوراثية ا ستجلبة قد تنقل صفات غ متكيفة مع نظم الإنتاج ا لية لأعلاف الذرة ، فإن خيار تطوير هجن لي x لي يبدو أك أ ية من غ ه. علية أقترح تعقيم الأصول ا لية بسيتوبلازمـ A3 للاستفادة من ا ستودع الضخم للتباين الوراثي ا لي للذرة الرفيعة، علي أن يسبق ذلك انتخاب مبدئي داخل الأصول ا لية لاستبعاد الصفات غ ا رغوبة أو تضمـ صفات سهلة التوريث مثل وفرة العصـ .

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1.0 Introduction

Sudan owns a huge herd of animal wealth estimated to be around 116 million head. It ranks first in the Arab World and second in Africa in livestock population. The natural pasture sector and crop residues are responsible for sustaining more than 90% of this wealth (National Comprehensive Strategy 'N.C.S.', 1999). Despite the meager contribution of irrigated forage in maintaining the national herd, its role is however, maximized by the high quality value of green forages as compared to feed stuff provided by other sources. Green forages play a unique role in upgrading and finishing of animals for export. The number of animals to be exported is some times limited by the quantity available of green forages[1]. The importance of the irrigated forage sector in the economy of the Sudan could be outlined in the following points:

- The sharp increase in the demand for animal products created by the ever rising population densities in urbanized centers.
- The growing market of animal export to the Arab World as could be seen from the large flows of animals to Khartoum State (Appendix 1). The N.C.S. aims at boosting animal products exports by twenty times compared to the present levels. It also aims at increasing the livestock

[1] Dr. Abdullah sid-Ahmed , Federal Minister of Animal Wealth. Mass media statement, Khartoum (2002).

population by three folds through upgrading the conventional methods employed by the traditional herd owners to more modernized techniques.

- Sudan can be recognized as having a great potential as a forage exporting country particularly to Gulf States. The bad need for forages to meet the flourishing industry of animal products in these countries was further accentuated by the policy of some of these countries to reduce the area under forage production.

As a result, the area under forage crops has recently witnessed a rapid increase both in the small holders and large specialized systems as well. Reliable records of acreage and tonnage at the national level are not available in the literature. However, taking Khartoum State as an example, the statistics of the Ministry of Agriculture and Animal Wealth for 2003 showed that the total area devoted to forage crops amounted to 120,000 feddan representing around 52% of the total area cultivated. A forage gap of about 800 thousand metric ton still exists despite this expansion (Appendix 2).

Sorghum [*Sorghum bicolor* (L). Moench] is the most important irrigated forage crop in the Sudan. A part from the natural vegetation, the sorghum straw "qassab" constitutes the bulk of the animal feed in the country (Bacon, 1948). Area wise, sorghum (mainly the traditional cultivar 'Abu Sab'in') covers the majority of the land cropped to forages. Abu Sab'in is a farmer-bred cultivar that has been exclusively grown for forage in areas near towns for many decades. Being a traditional cultivar, it is a highly mixed variety, with dry non-sweet stems and suffers from yield depression during winter season. Nevertheless, Abu Sab'in is a well adapted cultivar with some good agronomic characteristics.

Development of improved types of grain sorghum has been the main focus of research efforts in the Sudan during the past decades. Little or no attempts have been exerted to improve forage types. Considering the unique role of forage sorghum in sustaining the animal wealth of the country, and the great diversity of sorghum known to exist in the Sudan, it seems unrealistic to depend upon Abu Sab'in as the sole forage sorghum type in the Sudan.

Exploitation of heterosis in developing improved hybrid varieties is a well documented method for many crops. High yielding forage sorghum hybrids have been developed in many parts of the world. According to ElAhmadi *et al.* (2003), until the early eighties, Abu Sab'in has no competitor as forage sorghum in the Sudan. At the time Pioneer International Company introduced 'Pioneer 988', the hybrid was evaluated and released by the Agricultural Research Corporation " ARC " in1989 (Ishag,1989). Few years later, Pioneer International ceased to operate in the country and the hybrid was no longer marketed. Some introduced hybrids were later tested and released by the ARC. These were : 'Speedfeed' and 'Jumbo' from Pacific Seed Co. (Khair *et al.*, 1995), 'Pannar 888' from Pannar Seed Co. (Nour *et al.*,1998) and 'Safed Moti' from Proagro Seed Co. (ElAhmadi *et al.*,2003).

Although these hybrids proved to be good yielders, yet the farmer's preference was in favor of the traditional cultivar Abu Sab'in that seems to meet the requirements of the local market. Most of the introduced hybrids were mainly designed to suit the grazing or silage-making systems, whereas the prevailing system in the Sudan is the cut-and carry (green chopping) system. Other factors behind low adoption of introduced hybrids include unavailability and high cost of the seeds and poor extension services. Since all hybrids currently in use are introduced with no local production of their seeds, the development of local hybrids will greatly enhance the adoption process by making available cheap seed of better adapted hybrids. Up to date no locally developed hybrid has ever been released in the country. Such attempts are very limited and confined to some experimental hybrids being produced at the level of the faculties of agriculture at Khartoum and Gezira Universities. Research efforts to develop grain hybrid sorghum were, however, started more than two decades ago by the ARC in the frame work of ICRISAT-Sudan Project. These efforts had culminated in the release of the first Sudan-grain hybrid sorghum in 1983 (Ejeta, 1983). The released hybrid was of short combinable type, designed to suit the mechanized system and therefore of poor forage value. Therefore, this research study was undertaken with the following main objectives:

1. To investigate the possibility of developing forage sorghum hybrids using local stocks as pollinators and introduced genetic stocks sterilized

in A3 cytoplasm as females. The local materials are expected to add some characters that contribute to the adaptability of the newly developed hybrids. The A3 cytoplasm is a new male sterility source that has been available since early 1990s (Pedersen and Toy, 1997a). Unlike other sources of male sterility of which most, if not all of the present hybrids were developed, A3 has very few male restorers (Dahlberg and Madera-Torres, 1997). This allows production of male sterile hybrids, a situation that offers a theoretical possibility for quality improvement by eliminating seed as a strong carbohydrate sink. This suits nicely the green chopping system adopted for forage cultivation in the Sudan.

2. To study the magnitude of heterosis for different characters and to investigate the possibility of exploiting heterosis in breeding for improved forage sorghum
3. To perform a combining ability study using line x tester analysis to identify parents showing desirable general combing ability (GCA) and cross combinations with high specific combing ability (SCA). Hybrids with high SCA effects, if encountered, may possibly be used as direct candidates. Parents with the best desirable GCA effects may be advanced for further investigations.

2.0 Literature Review

2.1 Potential for forage sorghum improvement in the Sudan

There is strong evidence in the literature pointing to the great genetic diversity of sorghum spp. in the Sudan. (Bacon, 1948; Tahir, 1964; Abu-El-Gasim and Kambal, 1975; and Yasin, 1978). The most important types of forage sorghum in the Sudan include:

Grain Sorghums: Bacon (1948) reviewed forage crops in the Sudan. Many of the grain sorghum varieties can be grown as forage crops. According to Harlan and de Wet's (1972) classification the most widely grown forage cultivar 'Abu Sab'in' belong to the race Caudatum-Durra. The durras are known to have little forage value because the stalks are dry, non sweet and sparsely leafed. Abu Sab'in is a farmer-bred cultivar. According to Bacon (1948) the need for fodder influenced farmers to choose vigorous growing plants with finer stems which upon growing at higher seed rate produce a better forage crop. Kambal (2003) reported that the name of Abu Sab'in is used for two distinct sorghum cultivars grown for grain production at Rubatab and Alyab areas in Northern Sudan. The one grown at Alyab 'Dibekri' is also cultivated as forage crop in Khartoum and Gezira States. To avoid confusion, Kambal (2003) proposed to refer to Dibekri as 'Abu Sab'in Alyab' and to designate the other cultivar 'Abu Sab'in Rubatab'. Abu Sab'in tolerates a wide range of salinity under which the forage quality is further improved (Khair and Jarrel, 1987). Some heterogeneity exists within both types of Abu Sab'in (Kambal 2003). The present seed stock was subjected to great mechanical mixing with other durra seed leading to an obvious loss of the initial agronomic features of the variety. Selection within such population may result in isolation of lines with better yield and quality. This had been demonstrated by Kambal (1972). Another type of grain sorghum forages under the name 'Abu Kalleiga' was reported by Bacon (1948). Abu Kalleiga is a feterita type known of its ability for tillering and branching.

Wild Sorghums : Bacon (1948) stated that wild sorghums represent a wealth of good fodder grasses in the Sudan. Rao and Mengesha, (1979) reported that wild sorghums, which are lacking in the present world collection, are particularly abundant in the central Sudan. According to the report of the International Board for Plant Genetic Resources 'IBPGR' (1988) a collecting mission through Sudan, Ethiopia and Kenya obtained 346 accessions of forage sorghum mainly from the cultivated dual purpose '*Sativa*' and the wild loose-panicled types of *Sorghum bicolor* var. *bicolor*. Of these 106 were collected from Sudan and 136 from Ethiopia. The collected accessions included all available wild species and up to 15 hybrid weedy types. Bacon (1948) gave some details about wild sorghums in Sudan. This group comprises a number of annual and perennial grasses. The annual grasses comprise different types under the local name 'adar'. They have better tillering capacity and leafier stems. The adar grasses cross freely with the cultivated sorghum causing great deterioration in seed stocks. The traditional cultivar 'Garawi' is one of the adar types. According to Bacon (1948), Garawi provides excellent green forage or hay, does well on salty soils, less affected by stem borer and has better persistence or longevity. In addition, McDonald and Dale (1983) pointed that the risk of the hydrocyanic acid poisoning tends to be less with Sudan grass as compared to perennial grasses or grain sorghums. Sudan grass (*Sorghum sudanense*), the widely cultivated annual forage in the United States is one of the annual adar or Garawi types. As reported by Maunder (1983) its original seed lot had been introduced to the United States from Sudan in 1909 mainly to replace the perennial type Johnson grass. As pointed by Bacon (1948) the perennial grasses are similar in appearance to the annual adar, but have a perennial rhizome. This perennial habit can be a merit in forage production, but on the other side, may poses the threat of inducing weed problems especially in grain sorghum production areas.

Sweet Sorghum Forages : 'Ankolib' is the general term used for sweet sorghums in the Sudan. Rao and Mengesha (1979) conducted a germplasm collection expedition in eastern Sudan. They reported that Ankolib is a durra-bicolor characterized by sweet stalk just like sugar cane. It is a mixed land race variety grown mainly for chewing the juicy sweet stem (Kambal, 1972). Ankolib was rarely mentioned in the literature as a forage crop.

However, sweet sorghums are highly recognized for forage and syrup production in other parts of the world (Dwayne *et al.* 1999).

2.2 Breeding for sorghum improvement in the Sudan

The importance of sorghum as grain crop in the Sudan is well documented. Less so is its importance as a forage crop (ElAhmadi *et al.*, 2003). Sorghum research and development in the Sudan before 1975 was best reviewed by Mahmoud (1983). The work on crop management and pests control was the most prominent in the early days. Although collection of Sudanese sorghum land races was started by Punter as early as 1914, yet varietal improvement was not started until the early thirties with the introduction of the improved types from the USA. Research work on sorghum improvement really took off in 1952 with the foundation of the Central Rainlands Research Station at Tozi. The objectives were to develop high yielding combinable varieties to meet the growing need of the mechanized schemes. Selection within the local stocks for high yielding grain types constituted the bulk of research work at the beginning of the breeding program. Dwarf White Milo was released in the early sixties as a replacement to Wad Fahal, the popular but late maturing traditional variety. Three strains of Um Benein (T.U.B. 7, 11, and 22), one of Wad Akar (W. Akar 51/3) and one of Wad Yabis (W. Yabis 1) were distributed to the farmers. The transfer of sorghum breeding work to Wad Medani in early 1970s together with the cooperation of the international programs (ALAD, ICRISAT and INTSORMIL) gave sorghum breeding strong imputes. Ibrahim (1997) gave some information about sorghum improvement from 1970s to 1990s. Gadam Elhamam Improved and Dabar Improved were released in 1977. The period from 1985 to 1995 witnessed intensive sorghum breeding work and a number of improved open pollinated varieties were released. Some of these include El'Inqaz, Wad Ahmed, and Tabat.

Work on grain hybrid sorghum was done on a limited scale prior to the establishment of Tozi Research Station. Mahmoud (1983) attributed this to the absence of a full time sorghum breeder, limited supporting staff and shortage in research funds. However, Mohamoud (1983) reported that in 1960 he made six experimental hybrids using male-sterile 602 as a female with six local parents. Based on the results obtained, Mahmoud proposed an extended hybrid program but the proposal was rejected on the argument that farmers were too illiterate to handle hybrids. Mahmoud (1983) also reported that A.E. Kambal tried to develop some hybrids between popular Sudanese types and CK 60 as male sterile. Though most of these were of combinable height with acceptable grain, yet none of them showed outstanding yielding ability.

Ejeta (1983) discussed the development of grain hybrid sorghum in the Sudan. The real efforts in hybrid development were started after the ICRISAT-Sudan cooperative program was established in 1977. One of the program objectives was the development of early to medium maturing hybrids for irrigated and rain-fed environments using introduced females (A lines) and a diverse array of local and exotic pollinators. Short combinable types to meet the growing need of the mechanized sector were chosen. In 1983 one experimental hybrid (EEH-3) was officially released as the first commercial grain sorghum hybrid and renamed in Arabic 'Hageen Dura-1'. Ibrahim (1997) reported that another two hybrids were released in 1996, namely, Rabih for irrigated and rain-fed areas and Shikan for irrigated areas.

Forage sorghums research in the Sudan : Very few research efforts have been exerted to develop improved forage sorghum cultivars from the local stocks. Kambal (1972) studied the performance of two local forage types, namely, Abu Sab'in and Ankolib together with four forage varieties introduced from USA and six Abu Sab'in lines derived by single plant selection. Abu Sab'in was more productive than the introduced varieties averaging higher in dry matter production per day. The introduced varieties, on the other hand, were characterized by higher tillering capacity and finer juicy-sweet stems. The yield components that contributed most to the higher yield of Abu Sab'in were stem height and thickness. It was concluded that selection in Abu Sab'in was effective in isolating lines earlier in flowering, more productive and better in quality (juiciness and sweetness) than the original stock. In another trial Kambal (1984) studied the performance of Abu Sab'in, two introduced sweet sorghums, one local maize and pearl millet varieties during summer, kharif and winter seasons. The introduced sweet sorghum variety ‘Kansas Orange’ over yielded Abu Sab’in during summer and winter seasons. It was concluded that, 50 % increase in yield over the present practice of growing Abu Sab’in could be attained by growing the maize variety in winter, Kansas orange in summer and the millet variety in kharif.

Ibrahim and Orfi (1996) studied variability in forage yield over two sowing dates and two locations in ten sorghum cultivars. Eight of them were grain cultivars while the other two were forage cultivars namely, Abu Sab’in and the hybrid Pioneer 988. They presented data based on ranking procedure showing that Abu Sab’in and some grain cultivars were superior in forage yield compared to the hybrid Pioneer 988. Among grain cultivars, Saffra and Gadam Elhamam were considered the best yielders. They noticed a wide range of variability for most characters. The effect of sowing date was most pronounced compared to that of location especially for days to flower and plant height.

Forage sorghum hybrids in the Sudan : No evidence in the literature pointing to the release of a locally developed forage hybrid sorghum in the Sudan. Research work on forage hybrids was mainly confined to introduction and testing of exotic hybrids. Up to date four grain sorghum x Sudan grass hybrids were tested and released by the Agricultural Research Corporation (ARC) viz. Pioneer 988, from Pioneer International Co.

(Ishag,1989) followed by Speedfeed and Jumbo from Pacific seed Co. (Khair *et al.*, 1995), Panar 888 from Panar Seed Co. (Nour *et al.*,1998) and Safed Moti from Proagro seed Co. (ElAhmadi *et al.*,2003). Mohammed (2001) studied the agronomic performance of the introduced hybrids Panar 888, Speedfeed and Safed Moti in comparison to the local cultivar Abu Sab'in. The results showed that, the introduced hybrids were superior in yield compared to Abu Sab'in. Panar 888, though was not the best yielding hybrid, but was the earliest in flowering and showed the best average dry matter production per day. However Abu Sab'in showed increased seedling vigor compared to the introduced hybrids.

2.3 Development of hybrids in forage crops

Sprague and Tatum (1942), Allard (1960) and Briggs and Knowles (1967) discussed the development of hybrid varieties. Allard (1960) pointed that the first attempt to develop hybrid varieties was done in maize in late nineteenth century, but the practical exploitation of heterosis was delayed until the fourth decade of the twentieth century. The greatest development in hybrid varieties had been in maize. Allard (1960) attributed that to the combination of an exceptionally favorable mating system and striking heterotic response in F1 combinations.

Briggs and Knowles (1967) reviewed earlier stages of forage crops breeding. Sustained interest in forage crop breeding got under way after breeding techniques were well developed for self pollinated crops and development of hybrid varieties in maize. Earlier breeding methods of forage crops depend mainly on mass selection but the first serious attempt in developing breeding procedures suitable to forage crops was made by T. J. Jenkin in 1931 and later by L. E. Kirk in 1933 who employed the *strain building* method which was similar in many respects to the methods of developing synthetic varieties. The unique status of hybrid development in forage species was discussed by Allard (1960). Methods adopted in maize breeding could be applied to forage species; however, careful elimination of undesirable genotypes should precede progeny testing.

Hybrid sorghum : Allard (1960) mentioned that although heterosis has been known to exist in some self pollinated crops like sorghum, yet hybrid development in such crops had to await the advent of male sterility systems. Early history of hybrid sorghum development in the USA was reviewed by Maunder (1983). Research workers at Texas Experiment Station became aware of hybrid vigor in sorghum as early as 1920. The private hybrid seed industry of grain sorghum was soon started after the advent of cytoplasmic male sterility in 1954. According to Maunder (1983), the release of the first forage sorghum hybrids (Sudan grass as well as sweet sorghum hybrids) did not occur until 1959. These were the unwanted crosses of grain hybrid program which later led to the forage hybrid “Sudax”.

Cytoplasmic-genic male sterility (CMS) in Sorghum : The first CMS type (A1) in sorghum was developed by Stephens and Holland (1954) by transferring Kafir chromosome into Milo cytoplasm. The hazards of depending upon narrow cytoplasmic base have stimulated a search for new sources of CMS in sorghum. Rao (1962), Hussaini and Rao (1964) and Webster and Singh (1964) have reported different sources of CMS. In early 1990s, several sorghum lines male-sterilized in A3 have been available (Atkins, 1990 and Schertz *et al.*, 1990). A3 is an alternative cytoplasmic sterility source with very few restorers (Dahlberg and Madera-Torres, 1997). It differs from other CMS types in that it produces sterile F1 hybrids if grown in isolation, possibly resulting in high forage quality by eliminating seed as a strong carbohydrate sink. To exploit such benefits in forage breeding, Pedersen and Toy (1997b) released 29 forage sorghum genetic stocks sterilized in A3 cytoplasm. As reported by Pedersen and Toy (1997b) the broad genetic base of these genetic stocks allow direct utilization of these female lines for producing F1 hybrids, previously not possible on A1 cytoplasmic-sterile seed parents.

2.4 Combining Ability

Virmani (1994) pointed that combining ability is one of four methods employed by breeders to identify parents with good heterotic combinations.

The other three methods were: per se performance, mitochondrial complementation and genetic diversity (as determined geographically, morphologically or through biochemical markers). There are two types of combining ability viz., general (GCA) and specific (SCA) combining ability (Singh and Narayanan, 1993). As stated by Allard (1960), general combining ability became a practical method in hybrid development only after the adoption of the top cross method that allowed breeders to discard the lower-yielding half of the lines under test without serious risk of losing valuable material. The other promising half of the inbred lines is to be evaluated by specific combining ability to determine the best nicking set of crosses. According to Sprague and Tatum (1942) GCA refers to the average performance of a line in hybrid combinations, and SCA refers to those cases in which certain combinations are relatively better or worse than would be expected on the bases of GCA of their parents. Virmani (1994) stated that plant breeders mostly depend on tests of combing ability like diallel, line x tester and top cross tests, to determine parents for developing heterotic combinations. These field tests, as argued by Boppenmaier *et al.* (1992), are the most costly and time-consuming part in hybrid breeding program. He suggested that the efficiency of a hybrid breeding program could be increased by predicting superior crosses before field evaluation with the aid of biochemical markers screening techniques.

Combining ability for grain yield and related traits in sorghum had been extensively studied by many workers (e.g., Kambal and Webster, 1965; Liang, 1967; Beil and Atkins, 1967; Laosuwan and Atkins, 1977; Monyo *et al.*, 1988; Toure *et al.*, 1996; and Yu and Tuinstra, 2001). Combining ability for forage traits was not as much investigated as for grain traits. Few studies in this area could be traced in the literature (e.g., Blum, 1968; Gupta *et al.*, 1976; Dangi *et al.*, 1980 and Kang and Lee, 1997).

2.4.1 Combining ability in forage sorghum for yield and related traits

Preponderance of additive gene action in controlling forage yield was reported by Blum (1968), Gupta *et al.* (1976), Dangi *et al.* (1980) and Monpara and Sanghi (1982) whereas nonadditive gene action was reported by Sanghi and Monpara (1981) as being important in controlling forage yield.

Blum (1968) studied estimates of general (GCA) and specific (SCA) combining ability for forage yield under dry land conditions using grain sorghum as A-lines and sorgo (sweet sorghum) varieties as pollinators. GCA was found to be of major importance in controlling forage yield (GCA was 20.5 times greater than SCA effect) pointing to the importance of additive gene effects in determining forage yield. The variance of males (sorgo varieties) was 10.6 times greater than that of grain sorghum varieties indicating a greater effect of sorgo varieties on variances between crosses.

Assumption was drawn that variability within sorgo group has to be exploited first. Gupta *et al.* (1976) studied combining ability for forage yield and some related traits. He concluded that GCA variance was significant for all characters while SCA variance was significant only for green matter yield (GMY). The magnitude of the GCA variance was 2 to 12 times greater than that of SCA variance for GMY, indicating the predominance of additive gene action for this trait. Monpara and Sanghi (1982) studied combining ability in forage sorghum for fodder yield, days to flower, plant height, and other quantitative characters. They found that both GCA and SCA variances were highly significant for all characters under study. The variances due to GCA were higher than those due to SCA for all characters other than crude protein. High SCA effects for green and dry fodder yields were exhibited by the best performing hybrids. They suggested population improvement approach in the segregating generations to exploit the additive genetic variance which is present in a sizable portion for green and dry forage yield.

Mogami *et al.* (1974) noticed that combining ability effects for GMY differ with different sorghum groups. GMY in Hegari and sorgo groups was mainly governed by GCA of pollen parents. In Japanese native group GMY was governed by both GCA and SCA of pollen parents with GCA predominating. The same is true for Sudan grass group but with SCA predominating. Doi *et al.* (1974) studied combining ability estimates in hybrids produced from forage sorghum lines as females and native Japanese varieties as pollinators. GCA estimates were significant for plant height and stem diameter in both male and female parents. GCA estimates for forage yield were significant only in pollen parents. SCA estimates were not significant.

Sanghi and Monpara (1981) reported that additive genetic variance was predominant for number of tillers while nonadditive genetic variance was predominant for GMY, dry matter yield (DMY), days to flower, plant height and leaves traits. Gupta and Paliwal (1976) reported that dominance variance was more important in the expression of green forage yield. Kukadia and Singhania (1980) studied combing ability in quantitative characters in forage sorghum. They reported that over-dominance was involved in forage yield and other characters. Number of days to 50% flowering and leaf to stem ratio appear to be mainly controlled by dominant genes. Their results suggested that improvement of quality and yield in forage sorghum could be achieved by production of hybrids and reciprocal recurrent selection.

Kirby and Atkins (1968) studied combining ability for plant height, stalk diameter, days to mid bloom, and leaf number per plant. The results showed that significance was indicated more often for GCA than for SCA effects. Also, for nearly all characters, the mean squares for GCA were markedly larger than those for SCA. Liang (1967), Bijapur (1980) and Meng *et al.* (1998) reported significant GCA and SCA estimates for plant height and days to flower with additive effects appeared to be prominent in their inheritance. Shankaregowda *et al.* (1972a) studied combining ability in sorghum at two locations. They found that GCA was more important than SCA for plant height and number of days to flower. Differences over locations were observed for gene actions of different characters. Singhania (1980) reported variable GCA effects over locations. GCA effects were predominant for mature plant height and days to flowering.

2.4.2 Combining ability for forage quality traits

Ross *et al.* (1980) investigated forage quality characters in residues of hybrid grain sorghum with a view of relating agronomic characters before grain harvest, to quality characters of plants remnants left after harvest. He concluded that breeding high yielding grain hybrids with high quality stems for forage could be difficult. In another study, Ross *et al.* (1983) studied combining ability effects for forage residue traits in grain sorghum. GCA were reported to exceed SCA effects for protein of leaves and stems, *in vitro* dry matter disappearance and digestible dry matter yield of leaves and stems. They stated that an ideal hybrid with favorable agronomic and grain traits combined with highly favorable forage traits may be difficult to develop, but superior genotypes may evolve from intensive plant breeding. In a preliminary evaluation of residue yield and quality in grain sorghum lines and hybrids, Groz *et al.* (1979) reported a tendency for taller parental lines and hybrids to produce above-average yields of residue and grain. GCA and SCA effects were significant for most characters studied, with GCA being much greater than SCA estimates, indicating that additive gene effects were important in the expression of most characters.

Groz *et al.* (1987) studied the combining ability of mineral elements in forage sorghum. GCA exceeded SCA effects for N, Mg, Si, K, Ca, Mn, Cu and Zn. They concluded that altering the mineral content of forage sorghum by breeding is feasible.

Rao and Ahluwalia (1980) investigated the role of grain sorghum in breeding for improved quality and seed yield in forage sorghum. They reported a significant GCA and SCA variances for protein content and *in vitro* dry matter digestibility. The grain lines were better general combiners than the fodder lines for fodder quality characters. Gupta and Paliwal (1976) reported that dry matter digestibility, total soluble solids and dry-matter percentages were predominately governed by additive gene action. In another study Gupta *et al.* (1976) reported significant GCA variances for dry matter digestibility, total soluble solids, dry-matter and crude protein percentages, whereas SCA variances were significant only for crude protein and total soluble solids. Predominance of additive gene action in controlling crude protein and total soluble solids was suggested.

2.5 Heterosis

Definition and genetic causes : Allard (1960) defined heterosis as the converse of the deterioration that accompanies inbreeding. Briggs and Knowles (1967) defined heterosis as manifestation of heterozygosity expressed as increased vigor, size, fruitfulness and resistance to diseases, insects or climatic extremes. Sedcole (1981) defined heterosis as the increased vigor of F1 hybrid over the mean of its parents or the better parent. Virmani (1994) defined heterosis as the biological phenomenon in which an F1 hybrid of two genetically dissimilar parents showed increased vigor at least over the mid-parent value.

The genetic base of heterosis was discussed by many scientists (e.g. Allard, 1960; Briggs and Knowles, 1967; Moll and Stuber, 1974; Sedcole 1981 and Budak, 2002). Two possible genetic causes of heterosis were commonly emphasized by these scientists viz., partial to complete dominance and over-dominance. As stated by Allard (1960), the dominance theory was first proposed by some workers in 1908 and 1910 and was later supported by Jones in 1917. In this hypothesis heterosis was due to the complementary effect of a linked group of genes (provided by both parents) comprising some favorable dominants and some unfavorable recessives whereby the deleterious effects of the recessive alleles are hidden by the dominant alleles in the F1 hybrid. The over-dominance theory was proposed independently by Shull and East in 1908 and was later elaborated by East in 1936. In its simplest form, this hypothesis explains heterosis by assuming that the heterozygous locus is superior to either homozygous due to some physiological stimulus. Both hypotheses were criticized by some workers on the ground that each of them can not provide comprehensive explanation of heterosis. Crow (1948) and some workers gave some evidence against the dominance theory. They argued that the expected increase in vigor (based on dominance theory) can not be much more than 5%, which is far smaller than that observed. On the other hand, Sedcole (1981) reviewed in depth the theories of heterosis and displayed many findings against the over-dominance theory. He concluded that the original explanation of heterosis as outlined by Jones in 1917 still appears to be valid.

With the advent of recombinant DNA techniques, molecular markers and quantitative trait locus (QTL) investigations of heterosis became more advanced and informative (Tsaftaris, 1995). Epistasis and linkage were reported to be major contributors to heterosis (Yu *et al*. 1997; Tanksley and Monforte, 2000). However, explanation of heterosis depending on these techniques remained to be contradictable, but with more evidence supporting the dominance theory. Xiao *et al.* (1995) demonstrated that over-dominance is not a major cause of heterosis for yield in a cross between two subspecies of rice. Using QTL analysis, he found no correlation between most traits and overall genome heterozigosity. Evidence supporting the dominance theory of heterosis was also presented by Pickett and Galwey (1997) in wheat and Cramer and Wehner (1999) in cucumber. Stuber *et al.* (1992) utilizing RFLPs technique (restriction fragment length polymorphism) investigated the nature of heterosis using two BC1 populations of maize derived from the F3 of a cross between two inbred lines. He found a significant correlation between grain yield and the amount of heterozygosity. He concluded that over-dominance was the cause of heterosis in maize yield, although it was noted that pseudo-overdominance could not be ruled out as a contributor to heterosis. However, in a similar study in maize, Graham *et al.* (1998) reported contradicting results using introgression from the population used by Stuber *et al*. (1992). A third explanation of heterosis was given by Milborrow (1998). He suggested that the growth of a plant may be limited by the genes that regulate certain metabolic pathways down to lower levels than maximum possible. Heterozygotes may partially escape this regulation because they have two slightly different alleles for these genes, allowing greater flow on these pathways. Milborrow (1998) explained that this is not over-dominance, but similar to it in predicting that heterozygotes have an inherent advantage in vigor that can not be duplicated by an amount of selection in open-pollinated homozygous lines. According to this theory, the recessive genes being accumulated under the protection of linked dominant genes are not sub-lethal mutants, but necessarily, a part of the genetic adaptation of the population.

Budak (2002) stated that although conflicting reports about explanation of heterosis is clear from the literature, yet a common theme through out the last century has been that no one hypothesis of heterosis holds true for every experiment or every organism. He concluded that heterosis is very likely to be organism or population dependent, for example, heterosis observed in self pollinated species like rice may be different from that of naturally cross-pollinated crops like maize.

Estimation of heterosis : According to Singh and Narayanan (1993) heterosis is estimated in four different ways viz., over mid-parent (average heterosis), over better parent (heterobeltiosis), over commercial cultivar (useful heterosis) and over commercial hybrid (standard heterosis). The term heterobeltiosis was first coined by Fonseca and Patterson (1968). It was considered by Kambal and Abu-El-Gasim (1976) as more important since it implies the improvement of yield and other desirable characters over the exiting maxima. Sedcole (1981) emphasized heterobeltiosis much more than average heterosis since the latter could be simply predicted from heterobeltiosis, whereas the reverse may not necessarily be possible.

2.5.1 Heterosis in forage sorghum

Numerous studies of heterosis for grain yield in sorghum were undertaken (e.g. Quinby, 1963; Kambal and Webster, 1965; Niehaus and Pickett, 1966; Kambal and Abu-El-Gasim, 1976; Singhania, 1980 and Badhe and Patil, 1997). On the other hand few investigations on heterosis for forage yield in sorghum have been reported. Nevertheless, attributes related to both grain and forage yields have been investigated by many workers. (e.g., Kambal and Webster, 1966; Kirby and Atkins, 1968; Shankaregowda *et al*., 1972b; Kambal and Abu-El-Gasim, 1976; and Singhania, 1980).

Sangwan *et al.* (1972) studied heterosis in forage sorghum in 60 F1s hybrids. The data presented by them showed significant heterosis for forage yield. Some hybrids expressed heterotic effects for protein or sugar content. Chauhan and Singh (1973) studied heterosis in different sorghum spp. for characters associated with fodder components. They found that heterosis for fodder yields ranged from 2.69 to 44.2 percent. Hybrids approached the taller parents in height and exceeded the better parents in tillering capacity. Little or no heterosis over mid-parent or better parent was observed for leaf length, leaf width and internode diameter. In a fodder breeding program, Paroda *et al.* (1972) studied the genetic improvement in sorghum for earliness to flower, leaf number per plant, plant height, stem girth, tillering, leaf to stem ratio, yield and HCN content. Heterosis was noticed for most of the characters studied and hybrids gave 2.5 to 3 fold yield increase over mid-parent. Landi (1974) studied prospects of obtaining hybrids of 'Sudan grass x Sudan grass' type adapted to different climatic conditions. The developed hybrids gave at least double the mean yield of three used control varieties. There was a high correlation between the hybrids and their male parents for plant height and days to flowering. The earlier and the taller hybrids gave the highest yields. The study carried by Filatov and Larina (1974) revealed that in hybrids obtained by crossing early varieties, heterosis occurred for number and size of leaves and prolongation of growth period leading to doubling of the hybrids photosynthetic potential and an increase in its yield of green matter.

Scapim *et al*. (1998) studied heterosis for forage characters over two different planting dates. Differences in hybrids performance over the planting dates were noticed for most characters. Heterosis was positive for dry matter yield and negative for protein at the two planting dates. Shankaregowda *et al.* (1972b) studied heterosis in grain sorghum for a number of characters in different locations. Most of the hybrids expressed significant positive heterosis for plant height and significant negative heterosis for number of days to flower. They also noticed differences between locations in the magnitude of the expressed heterosis. Blum *et al.* (1990) evaluated heterosis over a wide environmental range to investigate the hypothesis that heterosis in biomass production of sorghum may be attributed to stability in carbon exchange rate. They concluded that when extreme stress conditions were developed, the hybrid's performance depends on its genetic background more than on heterosis.

Badhe and Patil (1997) studied heterosis over mid-parent and better parent for different characters in grain sorghum. Significant heterotic effects in positive direction were expressed for all characters studied. Most of the high heterotic combinations were between geographically diverse parents. Kambal and Webster (1966) studied manifestation of hybrid vigor in grain sorghum. They found that heterosis in positive direction was manifested for stem length but not for days to bloom. Hybrids were 4.5 inches taller and 2.5 days earlier than the mean of the parents. Kirby and Atkins (1968) examined comparative expression of heterosis for 13 vegetative and mature plant characters in grain sorghum. Significant average heterosis was expressed by the hybrids for mature plant height, stem diameter and leaf number taken at vegetative growth stage. Also hybrid exhibited longer and wider leaves giving more area per leaf and earlier blooming, but differences were not significant in comparison with the parental means. Kambal and Abu-El-Gasim (1976) reported that the most evident expressions of heterosis included increased plant height and increased vegetative growth associated with late flowering. However, they noticed that some of the hybrids were taller than their better parents and at the same time earlier than either parent, suggesting that was due to faster rate of cell division in the hybrids as compared to the parents. Borello *et al.* (1980) evaluated differences in earliness between parental lines and their hybrids. They found that there was a high correlation between the gain or loss of earliness in the hybrids relative to the earlier parent and the absolute value of a difference between parents. It was concluded that the closer the parents in earliness, the greater the gain in earliness in the hybrids. The study carried by Potresova (1971) showed that all hybrids were highly heterotic for length and breadth of leaf blades. The growing season of most hybrids tended to approach that of the later parent. With respect to plant height and growth habit, the hybrids were close to the taller parent and bushier parent respectively.

2.6 Genetic variability in forage sorghums

Genetic variability in forage yield and related traits in sorghum was studied by many workers (e.g. Phul *et al.*, 1972; Dharampal and Singh, 1973; Hussain and Muhammed Amin Khan, 1973; Doi *et al.*, 1974; Gupta and Sidhu, 1974; Paroda *et al.*, 1976; and Muhammad, 1990). Phul *et al.* (1972) reported that, fodder yield showed the highest genetic coefficient of variability and heritability estimate out of seven characters studied in 30 varieties. Low heritability estimates were observed for stem girth, leaf number per plant, leaf length and breadth, indicating that the scope for their improvement by selection was limited. Correlation between green fodder yield and these characters was positive. Stem girth, among other characters, contributes mostly to the fodder yield. Dharampal and Singh (1973) reported that green fodder yield was significantly and positively correlated with plant height and stem girth. Hussain and Muhammed Amin Khan (1973) reported significant positive correlation between green forage yield and number of tillers per plant, plant height and leaf number per plant. Gupta and Sidhu (1974) studied association among African, American and Indian forage sorghum types. They reported that, in Indian varieties, green fodder yield depends only on leaf number per plant, stem thickness and earliness, whereas in African varieties, green fodder yield was related to stem thickness and number of tillers per plant. They concluded that leafiness and number of tillers are more important than stem thickness in the selection of high yielding green fodder lines.

Paroda *et al.* (1976) recommended that in breeding for forage sorghum, the ideotype should have a high leaf to stem ratio, numerous broad and long leaves per plant, intermediate flowering date, a medium thick stem and moderate plant height.

Ibrahim and Orfi (1996) studied variability and characters association of forage yield components in some sorghum cultivars. The highest broad sense heritability estimate was shown by plant height and the lowest was exhibited by total fresh weight. Most characters were highly and significantly affected by season, location, cultivar, and their interactions. The main determinants of forage yields were : fresh weight per plant, plant height and thickness of the main stem.

Muhammed (1990) studied forage yield, grain yield and forage quality in 45 cultivars representing grain, dual-purpose and forage sorghums. Grain type cultivars produced better quality forage than both dual and forage cultivars. Forage yield and forage quality were occasionally negatively correlated, however, favorable positive association between maximum forage yield and quality were observed. He concluded that cultivation of dual-purpose and grain type cultivars was the best compromise between forage yield, grain yield and forage quality. Vidal and Lazarte (1975) reported positive but non-significant correlation between protein content and green forage yield. A negative but non-significant correlation was also noted between green forage yield and neutral detergent fiber.

3.0 Materials and Methods

3.1 Plant materials

Females (Lines)

Twenty nine forage sorghum genetic stocks in A3 cytoplasm together with their fertile counterparts were received from J. F. Pedersen, USDA-ARS, Department of Agronomy, University of Nebraska, USA (Appendix 3). According to Pedersen and Toy (1997b), these genetic stocks represent a broad range of forage sorghum lines in A3 cytoplasm and have the immediate application as females to produce F1 hybrids, many of which will show heterotic combinations previously not possible on A1 cytoplasmic male-sterile seed parents. The material was grown at the Experimental Farm of Shambat Research Station in July 2001. The females were tested for male sterility and their fertile counterparts (recurrent parents) were screened for general agronomic performance. All the females proved to be 100 % male sterile. According to the performance of their fertile counterparts (Appendix 4), seven male sterile lines were chosen to be used as females in this study. The selection criteria included characters contributing to increased forage yield as well as quality attributes. The selected lines were : Blue Ribbon, Hastings, Sugar Drip, Dale, N100, E-35-1, and N109. The first five females were selected for their reasonable plant height and most of which are of sweet sorghum type, characterized by highly sweet-juicy stems. N 109 and

E-35-1 were chosen for their apparent leafiness and white seed color (white seed color has marketing preference). Table 1 reflects the genetic stock designation, recurrent parent and cytoplasm source of the seven selected females.

Males (Testers)

A source population comprising the two major types of the traditional cultivar ‘Abu Sab’in’ viz. ‘Alyab’ and ‘Rubatab’ was established in Oct. 2000. About 200 single plant selections were made for vigorous, tall, juicy (green mid-rip), healthy, early and late flowering plants. The progeny of each plant was tested in a breeding nursery established in July 2001. Of these, S. 70 of Alyab and S. 186 of Rubatab type were chosen to be used in this study. The other two testers were : ‘Garawi’, a cultivated forage type of Sudan grass (*Sorghum sudanense* (Piper) Stapf) and ‘Ankolib’, a local sweet sorghum cultivar, grown mainly for chewing the sweet stalks. Garawi and Ankolib are heterogeneous traditional cultivars with broad genetic base, desirable for providing information about the general combining ability of a line. Abu Sab’in selections, on the other hand, are expected to show good performance in specific hybrid combinations with the selected lines. Table 2 shows some details of the materials used as males.

Standard check

The widely used commercial hybrid 'Panar 888' was used as a standard check. It was developed by the Panar Seed Company of South Africa and released by the Agricultural Research Corporation in 1998 ((Nour *et al.*, 1998)). It was characterized by its high dry matter production per day compared to other commercial hybrids used in the Sudan (Mohammed, 2001).

Production of F1 hybrid seed

A crossing block comprising the seven females (lines) and the four males (testers) was established in Dec. 2001 at the Experimental Farm of Shambat Research Station (Sh. R. S.). To insure optimum synchronization in flowering, the sowing time was varied based on the expected flowering time of parents. Heads of the female plants were covered prior to anthesis using pollination bags. At the appropriate time, the heads were hand pollinated and immediately recovered. F1 seed from the 28 crosses were collected.

3.2 The experiment

The experiment was grown for two years (2002 and 2003) and at two locations in Khartoum State viz., Shambat (Experimental Farm of Sh.R.S. lat.15°39' N; Long. 32°31'E) and Islang (35 kilometer north of Shambat). The soil at Shambat site is heavy clay with pH 8.5. The physical properties of Islang soil varies from silty clay to silty loam. At Islang the site has been under continuous cropping with Abu Sab'in for the past three seasons. Temperature, rain fall and relative humidity of the two growing seasons at Shambat site are presented in Appendix (5). The growing season of the year 2002 compared to that of 2003 was characterized by increased maximum temperature, reduced total rain fall and low relative humidity.

In the year 2002, sowing date was on the 12^{th} and 25^{th} of July at Shambat and Islang respectively, while in the year 2003, sowing date was on the 24^{th} of June and 11^{th} of July at Shambat and Islang respectively. Apart from that, the following methods and materials were similar for different years and locations.

The 28 hybrids together with their 11 parents plus the commercial hybrid 'Panar 888' were arranged in a randomized complete block design with three replicates. The plot size was 7.5 x 0.7 m ridge. Three to four seeds were sown in holes spaced at 10 cm along the ridge. The plants were later thinned to one plant per hole. Nitrogen (urea) was applied two weeks after sowing at a rate of 55 kg N/ha. Two sprayings against stem borers were applied on the second and the fourth week after sowing, using Sevin 85 at a rate of 1.9 kg/ha. The experiment was weeded twice and watered every 7 to 10 days. Harvesting was carried out 15 days after each entry had completed 50% flowering, which simulates the common farmer practice.

3.3 Data collection

Agronomic traits

1. Days to flower: Taken when 50% of the plants in the whole plot started to shed pollens.

Before harvest, five plants were randomly chosen from each plot to estimate plant height, stem diameter and number of tillers per plant as follows

2. Plant height (cm): Measured from ground level to the tip of the head.

3. Stem diameter (cm): Taken as the thickness of the stalk at the middle of the fourth internode from the plant base using a vernier caliper.

4. Number of tillers per plant: Number of tillers emerging from the main stem.

5. Green matter yield (GMY) : In metric ton/ha, estimated from 6.5 m harvested from each plot leaving 0.5 m from each side. Cutting was done at 5 to 7 cm above the ground level.

6. Leaf to stem ratio (percentage) : Estimated on dry weight basis, three plants were randomly selected from the harvested plot. Leaves were separated from the stems. Average dry weight of leaves (DWL) and stems (DWS) were determined. The ratio of leaf to stem was determined using the following formula :

Leaf to stem ratio = [DWL / (DWS+DWL)] X 100

7. Dry matter yield (DMY) : In metric ton/ha, estimated from a random sample of 0.5 kg taken from the harvested plot after determining GMY and oven-dried at 75°c for 48 hours.

8. Regrowth : In gram per meter row, evaluated on dry weight basis after 15 days from the date of cutting for each treatment. New emerging shoots in three meter row, randomly chosen from each plot, were harvested and air dried and the average dry weight per meter row was determined.

Proximate analysis for forage quality traits

Five forage quality traits of the hybrids and their parents were studied on dry matter basis, using material from two replicates of the experiment conducted in the year2002 at Shambat. The samples taken to estimate the dry matter yield were used for the analysis. The percentages of the following quality traits were determined :

1. **Neutral detergent fiber (NDF),**
2. **Crude fiber (CF),**
3. **Crude protein (CP),**
4. **Ash,**
5. **Ether extracts (E.E).**

Proximate analysis for the five forage quality traits was determined following the standard procedure of the A.O.A.C. (1980). Crude protein (CP) was analyzed using micro- Kjeldhal method. The CP in each sample was estimated from total nitrogen (the numerical conversion factor = 6.25). The chemical analyses were carried out in the laboratory of the Animal Production Research Centre at Kuku.

3.4 Statistical analysis

Single analysis of variance was performed for all characters before doing the combined analysis following the standard procedure of analyzing RCB design. The single analysis of variance revealed that differences between genotypes were significant for all characters, showing the feasibility for using line x tester analysis. However, the test for homogeneity of variance (Snedecor and Chocran, 1967) indicated that error mean squares for three characters, namely, stem diameter, number of tillers per plants and regrowth showed heterogeneity of error variance over years. However, since their error variances were homogeneous over locations, a combined analysis over locations was carried for the three characters. The other characters were subjected to combined analysis over years and locations. General Linear Model (GLM) of the statistical package AGROBASE generation II (2001-2003) was used for the analysis. Tables 3 and 4 show the salient features of the combined analysis of variance.

Combined line x tester analysis of variance

Combined line x tester analysis of variance over years and locations was carried out for the 28 hybrids and their 11 parents (the standard check was not included). Test of homogeneity of error variance after removing the standard check indicated heterogeneity of error variance over years and locations for tillering and regrowth; hence, the two characters were reported on single year basis. The entry and its interaction with year and location were subdivided into variations due to hybrids and parents. Similarly, the hybrid source of variation was partitioned to variations due to lines, testers and line x testers. Table 5 shows the form of the combined line x tester analysis of variance.

Combining ability from combined analysis of variance

General and specific combining abilities from combined analysis over years and locations were carried following the procedure of Beil and Atkins (1967) which is comparable to the analysis of a two-way classification model with interaction, with the interaction component being a measure of the specific combining ability effects. Estimate of the general combing ability of a tester (male) was obtained in terms of its performance in F1 hybrid combinations with all possible lines (females). Likewise, the general combining ability of a line was determined in terms of its performance in F1 hybrid combinations with all possible testers.

The linear model (Beil and Atkins, 1967) assumed for this analysis is as follows:

$$Y_{ijklq} = u + g_i + g_j + s_{ij} + l_l + y_q + r_{klq} + (gl)_{il} + (gl)_{jl} + (sl)_{ijl} + (gy)_{iq} + (gy)_{jq} + (sy)_{ijq} + (gly)_{ilq} + (gly)_{jlq} + (sly)_{ijlq} + e_{ijklq}$$

where:

i = tester = 1, 2,….4

j = line = 1, 2,….7

l = location = 1, 2

y = year = 1, 2

k = replicate = 1, 2, 3

Y_{ijklq}: denotes the value of the k th experimental unit of the progeny of a mating of the i th tester with the j th line in the l th location and the q th year,

u = an effect common to all hybrids in all replicates,

g_i = an effect common to all progeny of the i-th tester,

g_j = an effect common to all progeny of the j-th line,

s_{ij} = an effect specific to the progeny of mating the i-th tester with the j-th line,

l_l = the average effect of the l-th location,

y_q = the average effect of the q-th year.

The interaction terms of the model have meanings in context with these descriptions and are designated by the appropriate subscripts.

The lines and testers used in this study were considered as fixed effects. Years and location were considered as random effects. Table 6 shows the form of the combined analysis of variance used to estimate the variances of general and specific combining abilities.

General combining ability (GCA) and specific combining ability (SCA) effects were determined for each trait as follows:

GCA lines (L) $= \bar{x}_j - \bar{Y}$

GCA tester (T) $= \bar{x}_i - \bar{Y}$

SCA (L x T) = $\bar{x}_{ij} - \bar{x}_j - \bar{x}_i - \bar{Y}$, Where :

$\bar{x}_j$: = the mean of hybrid with a given line (female) averaged over all replications, years, locations and testers (males),

$\bar{x}_i$: = the mean of hybrid with a given tester (male) averaged over all replications, years, locations and lines (females),

$\bar{x}_{ij}$: = the mean of a given hybrid (L x T) averaged over replications, years and locations,

$\bar{Y}$: = the experimental mean.

Standard errors (SE) for general and specific combining ability were calculated following Groz *et al*. (1987) as follows :

SE (lines) = $(M_{fyl} / rmyl)^{½}$,

SE (testers) = $(M_{myl} / rfyl)^{½}$,

SE (line x tester) = $(M_{fmyl} / ryl)^{½}$

Where:

M_{fyl} and M_{myl} are the respective mean squares of line x year x location and tester x year x location divided by number of observations (replicates, years, locations, males or females).

M_{fmyl} is the mean square for (line x tester) x year x location divided by number of observations (replicates, years, locations).

The critical difference (C.D.) was calculated following Singh and Chaudhary (1985) where C.D. = SE x t (tabulated). If the absolute effect of GCA or SCA is greater than the C.D., it is considered significantly different from zero.

Combining ability from single line x tester analysis

Combining ability from single analysis of variance was based on the procedure developed by Kempthorne (1957) and as per the working example described by Singh and Chaudhary (1985). The form of analysis of variance and mean square expectations for individual experiment are reflected in Tables 7 and 8 respectively.

The model used to estimate GCA and SCA effects of the (ij) observation is as follows

$X_{ij} = u + g_i + g_j + s_{ij} + e_{ij}$

Where :

u = population mean,

g_i = GCA effects of the i^{th} tester,

g_j = GCA effects of the j^{th} line,

s_{ij} = SCA effects of the $(ij)^{th}$ combination,

e_{ij} = error associated with the observation.. X_{ij}

i = tester 1,2,3,.......i

j = line 1,2,3,.......j

The analysis is based on individual observation of the ij^{th} hybrid combination over replications.

GCA effects for lines

$g_j = x_j / tr - X\ldots / L\, t\, r$

where,

x_j = total of the j^{th} lines over all testers

X… = grand total of all ij^{th} hybrid combination over replications.

L = number of lines

t = number of testers

r = number of replications

GCA effects for testers

$g_i = x_i / L\, r - X\ldots / L\, t\, r$

where,

X_i = total of the i^{th} testers over all lines

SCA effects

$$S_{ij} = \frac{X_{ij.}}{r} - \frac{X_{i..}}{tr} - \frac{X_{.j.}}{L\,r} + \frac{X_{...}}{L\,t\,r}$$

Where, $X_{ij} = (ij)^{th}$ combination.

Standard errors for combining ability effects

S.E. (gca for line) $= (M_e/r \times t)^{1/2}$

S.E. (gca for tester) $= (M_e / r \times L)^{1/2}$

S.E. (sca effects) $= (M_e / r)^{1/2}$

S.E. $(g_i - g_j)$ line $= (2 M_e / r \times t)^{1/2}$

S.E. $(g_i - g_j)$ tester $= (2 M_e / L \times r)^{1/2}$

S.E. $(s_{ij} - s_{kl})$ $= (2 M_e / r)^{1/2}$

Where, Me = error mean square.

Proportional contribution of lines, testers, and their interactions to total variance

$$\text{contribution of lines} = \frac{\text{sum of squares (lines)}}{\text{sum of squares (crosses)}} \times 100$$

$$\text{contribution of testers} = \frac{\text{sum of squares (testers)}}{\text{sum of squares (crosses)}} \times 100$$

$$\text{contribution of lines x testers} = \frac{\text{sum of squares (lines x testers)}}{\text{sum of squares (crosses)}} \times 100$$

Estimation of Heterosis

Heterosis estimates were worked out following Singh and Narayanan (1993) as follows:

Average Heterosis = $[(F_1 - MP)/MP] \times 100$,

where, F_1 is the mean value of a hybrid and MP is the mean value of the two parents involved in the that hybrid.

Heterobeltiosis = $[(F_1 - BP)/BP] \times 100$,

Where, BP is the mean value of the better parent of the particular hybrid.

Standard Heterosis: Estimated over the standard commercial hybrid as follows: $[(F_1 - SH)/SH] \times 100$, where SH is the mean value of the standard commercial hybrid 'Panar 888'.

Test of significance for heterosis was done following Singh and Narayanan (1993) by comparing the value of the C.D with the difference between F_1 and the parent used for the estimation of heterosis. If the difference is greater than the C.D., heterosis is considered significant.

Table 1. Genetic stock designation, recurrent parent and cytoplasm source of the seven female parents used as lines in the study

Genetic stock	Recurrent parent	Cytoplasm source	Pericarp color	Mid-rib color
A3N166	Blue Ribbon	A3Tx 398	brown	G*
A3N168	Hastings	A3Tx 398	brown	G
A3N169	E-35-1	A3Tx 430	white	G
A3N159	N 100	A3Tx 398	brown	G
A3N173	N 109	A3Tx 398	white	G
A3N154	Sugar Drip	A3Tx 398	brown	G
A3N151	Dale	A3Tx 398	brown	G

* : G = green

Table 2. The genotype used as testers in the study

Genotype	Source population	Location / State	Pericarp color	Midrib color
S.70	Abu Sab'in 'Alyab'	Matamma (Nile State)	White	G
S.186	Abu Sab'in 'Rubatab'	River Atbara (Nile State)	White	G
Garawi	Sudan grass	El Diwem (White Nile State)	Brown	G
Ankolib	Common type	Sinnar area (Blue Nile Sate)	Brown	G

Table 3. Form of the combined analysis of variance over years and locations

Source of variation	d.f.
Location (Lo)	(Lo-1)
Year (Yr)	(Yr-1)
Block (B) in Lo x Yr	Yr Lo (B-1)
Lo x Yr	(Lo-1) (Yr-1)
Entry (E)	(E-1)
Yr x E	(Yr-1) (E-1)
Lo x E	(Lo-1) (E-1)
Lo x Yr x E	(Lo-1) (Yr-1) (E-1)
Error	Yr Lo (B-1) (E-1)

Table 4. Form of the combined analysis of variance over locations

Source of variation	d.f.
Location (Lo)	(Lo-1)
Block (B) in Lo	Lo (B-1)
Entry (E)	(E-1)
Lo x E	(Lo-1) (E-1)
Error	L o (B-1) (E-1)

Table 5. Form of the combined line x tester analysis of variance over years and locations

Source of variation		d.f.
	Year (Yr)	yr-1
	Location (Lo)	lo -1
	Yr x Lo	(yr-1) (Lo -1)
	Block (Lo x Yr)	yr lo (b-1)
	Entry (E)	e-1
Parent (P)		p-1
Hybrid (H)		h-1
P vs H		(e-1) - (h-1) - (p-1)
	Yr x E	(yr-1) (e-1)
Yr x H		(yr-1) (h-1)
Yr x P		(yr-1) (p-1)
	Lo x E	(lo -1) (e-1)
Lo x H		(lo -1) (h-1)
Lo x P		(lo -1) (p-1)
	Yr x Lo x E	(yr-1) (lo -1) (e-1)
Yr x Lo x H		(yr-1) (lo -1) (h-1)
Yr x Lo x P		(yr-1) (lo -1) (p-1)
	Line (L)	l-1
	Tester (T)	t-1
	L x T	(l-1) (t-1)
	Yr x L	(yr-1) (l-1)
	Yr x T	(yr-1) (t-1)
	Lo x L	(lo -1) (l-1)
	Lo x T	(lo -1) (t-1)
	Yr x Lo x L	(yr-1) (lo -1) (l-1)
	Yr x Lo x T	(yr-1) (lo -1) (t-1)
	Yr x L x T	(yr-1) (l-1) (t-1)
	Lo x L x T	(lo -1) (l-1) (t-1)
	Yr x Lo x L x T	(yr-1) (lo -1) (l-1) (t-1)
	Error a^1	yl (b-1) (h-1)
	Error a^2	yl (b-1) (e-1)

a^1 = error term for line x tester analysis

a^2 = general error term

Table 6. Form of the combined analysis used to estimate variance of GCA for lines (L), testers (T) and SCA (L x T) based on F1 hybrid data obtained over years (Yr) and Locations (Lo)

Source of variation	d.f.	Expectations of mean squares*
$Line_{gca}$ (gj)	6	$\delta^2 + r\delta^2_{sly} + ly\delta^2_{sy} + yr\delta^2_{sl} + lyr\delta^2_{s} + mr\delta^2_{gjly} + mlr\delta^2_{gjy} + myr\delta^2_{gjl} + mlyr\delta^2_{gj}$
$Tester_{gca}$ (gi)	3	$\delta^2 + r\delta^2_{sly} + ly\delta^2_{sy} + yr\delta^2_{sl} + lyr\delta^2_{s} + fr\delta^2_{gily} + flr\delta^2_{giy} + fyr\delta^2_{gil} + flyr\delta^2_{gi}$
L x T_{sca} (Sij)	18	$\delta^2 + r\delta^2_{sly} + lr\delta^2_{sy} + yr\delta^2_{sl} + lyr\delta^2_{s}$
Yr x L	6	$\delta^2 + r\delta^2_{sly} + lr\delta^2_{sy} + mr\delta^2_{gjly} + mlr\delta^2_{gjy}$
Yr x T	3	$\delta^2 + r\delta^2_{sly} + lr\delta^2_{sy} + fr\delta^2_{gily} + flr\delta^2_{giy}$
Lo x L	6	$\delta^2 + r\delta^2_{sly} + yr\delta^2_{sl} + mr\delta^2_{gjly} + myr\delta^2_{gjl}$
Lo x T	3	$\delta^2 + r\delta^2_{sly} + yr\delta^2_{sl} + fr\delta^2_{gily} + fyr\delta^2_{gil}$
Yr x Lo x L	6	$\delta^2 + r\delta^2_{sly} + mr\delta^2_{gjly}$
Yr x Lo x T	3	$\delta^2 + r\delta^2_{sly} + fr\delta^2_{gily}$
Yr x LxT	18	$\delta^2 + r\delta^2_{sly} + lr\delta^2_{sy}$
Lo x LxT	18	$\delta^2 + r\delta^2_{sly} + yr\delta^2_{sl}$
Yr x Lo x LxT	18	$\delta^2 + r\delta^2_{sly}$
Pooled error	216	$\delta 2$

* : r, m, and f, are the number of replications, males and females respectively . For other abbreviations, see the linear model assumed for the analysis, page 42

Table 7. Form of the single line x tester analysis of variance

Source of variation	d.f.
Block (B)	b-1
Entry (E)	e-1
Parents (P)	p-1
Parents vs crosses	1
Hybrids (H)	h-1
Line (L)	(L -1)
Tester (T)	(t-1)
Line x tester	(L -1)(t-1)
Error	(b-1)(e-1)
Total	b (e-1)

Table 8. Mean square expectations from single line x tester analysis of variance used to estimate variances due to GCA for lines (L), testers (T) and SCA (L x T)

Source of variation	d.f.	MS	Expected mean squares *

Line (L)	L -1	M1	$\sigma^2 e + \sigma^2 \iota\tau + t\, \sigma^2 \iota$
Tester (T)	T -1	M2	$\sigma^2 e + \sigma^2 \iota\tau + \mathbf{L}\, \sigma^2 \tau$
L x T	(L -1)(T -1)	M3	$\sigma^2 e + \sigma^2 \iota\tau$
Error	L T (r-1)	M4	$\sigma^2 e$

* : **L** and t are number of lines and testers respectively. $\sigma^2\iota$, $\sigma^2\tau$ and $\sigma^2\iota\tau$ are variances due to lines, testers and lines x testers respectively

4.0 Results

4.1 Agronomic performance

Table 1 shows mean squares for different characters studied obtained form single analysis of variance. The differences among entries were significant ($p < 0.01$) for all characters in each year, at both locations.

Combined analysis of variance was performed across years and locations for five out of eight traits, namely, green matter yield (GMY), dry matter yield (DMY), number of days to flower, plant height and leaf to stem ratio. The other three traits (stem diameter, number of tillers per plant and regrowth) were combined only over locations since their error variances were heterogeneous over years.

Mean squares of the combined analysis of variance across years and locations for the five characters are presented in Table 2. Significant ($p <0.01$) differences among entries were detected for all characters. Locations and years effects were significant ($p <0.01$) for all characters with the exception of the effect of years on DMY. Year x entry interaction was significant (mostly $p < 0.01$) for all characters, however, location x entry and year x location x entry interactions were insignificant. The interaction of locations x years was significant ($p < 0.01$) only for number of days to flower and plant height.

Table 3 shows mean squares of the combined analysis of variance over locations performed in each year for stem diameter, number of tillers per plant and regrowth. Significant differences ($p < 0.01$) among entries were detected in both years for the three characters. In both years, the effect of location was significant ($p < 0.01$) for stem diameter and non significant for regrowth, while for number of tillers per plant, it was only significant ($P < 0.05$) in the first year. The location x entry interaction was not significant in both years for the three characters.

4.1.1 Forage Yield

Tables 4, 5, 6 and 7 show the results for green matter yield (GMY) and dry matter yield (DMY) of hybrids, their parents and the commercial hybrid 'Panar 888' obtained in each year at both locations. Tables 8 and 9 show the respective GMY and DMY of the entries averaged over years and locations, with the data subjected to Duncan's multiple-range test.

Green matter yield (GMY) : The GMY of hybrids ranged from 29.8 to 50.1 t/ha and that of parents ranged from 16.5 to 38.6 t/ha. The hybrids E-35-1 x S. 70, E-35-1 x S. 186, E-35-1 x Garawi and Dale x S. 70 gave the highest GMY, averaging 50.1, 48.8, 48.3 and 45.6 t/ha, respectively. These yields were significantly higher than that of the commercial hybrid ‘Panar 888’ (40.3 t/ha). Other hybrids out-yielding the check hybrid ‘Panar 888’ include Sugar Drip x Ankolib, Hastings x S.70 and E-35-1 x Ankolib. However, their yields were not significantly different from Panar 888. Among parents, S.70 was the highest yielding, averaging 38.6 t/ha. Its GMY was significantly higher than that of Sugar Drip x Garawi and N 100 x S. 186, which were the lowest yielding hybrids. Generally, Most of the hybrids involving the male parent S.70, gave higher GMY than those involving other male parents. Among female parents, E-35-1 was the highest yielding, averaging 30.9 t/ha. Its GMY was significantly higher than Ankolib (23.5 t/ha), which was the lowest yielding male parent. The male parents (local material) were generally high yielding than the female parents (exotic material). Tables 4, 5, 6 and 7 indicated that the female parent N 109 kept the lowest value for GMY in each year at both locations. Consistent performance in GMY could also be noticed for many hybrids especially those involving the female parent E-35-1. However, the hybrid Blue Ribbon x Ankolib performed differently over years. As shown in Tables 4, 5, 6 and 7, the hybrid Blue Ribbon x Ankolib was the highest in GMY in the year 2002 at Shambat and Islang , averaging 51.8 and 49.3

t/ha, respectively, while in the 2003, it was surpassed by many hybrids, showing moderate GMY of about 38 and 34 t/ha at Shambat and Islang, respectively.

Dry matter yield (DMY) : The DMY of hybrids ranged from 3.86 to 6.68 t/ha and that of the parents ranged from 2.08 to 4.91 t/ha. The entries performed in the same relative order as in GMY. However, some exceptions could be noticed, especially the hybrids Hastings x Garawi, N 109 x S.70 and the female parent E-35-1. The highest DMY was shown by the hybrids : E-35-1 x S.70, E-35-1 x Garawi, Dale x S.70 and E35-1 x S.186, averaging 6.68, 6.54, 6.28 and 6.17 t/ha, respectively. These yields were significantly higher than the commercial hybrid 'Panar 888' (5.2 t/ha). Sugar Drip x Garawi was the lowest yielding hybrid, giving DMY of 3.86 t/ha. The male parent S.70 gave 4.91 t/ha, which was significantly higher than N 109 x Garawi, Hastings x S.186, N 100 x S.186 and Sugar Drip x Garawi. Among females, the parent E-35-1, significantly showed the highest DMY (4.28 t/ha). The female parent N 109 was the lowest yielding in the whole tested material, giving DMY of 2.08 t/ha.

4.1.2 Yield related traits

Tables 4, 5, 6 and 7 show the mean values for number of days to flower, plant height, stem diameter, number of tillers per plant, leaf to stem ratio and regrowth, obtained for different entries in each year, at both locations. Table 10 represents the performance of entries for number of days to flower, plant height and leaf to stem ratio, averaged over years and locations. Table 11 shows the average performance of entries over locations in each year, for stem diameter, number of tillers per plant and regrowth. Only those results presented in Tables 10 and 11 will be highlighted further.

Number of days to flower : Days to flower of hybrids ranged from 53.3 to 79.8 days and that of parents ranged from 54.4 to 82.5 days. The female parent E-35-1 was the latest to flower in the whole material, showing a value of 82.5 days. Among hybrids, Hastings x Ankolib followed by E-35-1 x Ankolib and E-35-1 x S.70 were the latest to flower, with respective values of 79.8, 77.6 and 74.3 days. The commercial hybrid 'Panar 888' flowered at 67.6 days and was significantly later in flowering than most of the tested hybrids. The hybrid Blue Ribbon x S.186 was the earliest to flower in the whole material, showing a value of 53.3 days. Among male parents, S.186 was significantly the earliest in flowering (54.4 days) and was also significantly earlier than many hybrids. Among female parents, Blue Ribbon was the earliest to flower. On the other hand, Dale from females, and S.70 and Ankolib from males, were significantly later in flowering than most of the hybrids, with respective values of 71, 67.2 and 66.4 days.

Plant height : Plant height of hybrids ranged from 216 to 253 cm. and that of the parents ranged from 116 to 233 cm. The hybrid E-35-1 x S.186 exhibited the highest value for plant height (253 cm) followed by E-35-1 x Garawi (247 cm). The lowest value for plant height among hybrids was shown by the hybrids N 100 x S.186 (216 cm) and Hastings x Ankolib (218 cm). Most of the tested hybrids were significantly taller than the commercial hybrid 'Panar 888' that showed a value of 217 cm. Most of the male parents were significantly taller than the female parents. The female parent N 109 showed the lowest value for plant height in the whole material tested (116 cm).

Leaf to stem ratio : Leaf to stem ratio ranged from 34.4 % to 43.8 % for the hybrids and from 32.6 % to 53.7 % for the parents. Most of the female parents expressed high values for leaf to stem ratio. The female parent N109 showed the highest value for leaf to stem ratio in the whole material tested followed by E-35-1 and Sugar Drip, with respective values of 53.7 %, 46.1 % and 44.9 %. Among hybrids, the highest value was expressed by N 100 x Ankolib (43.8 %) followed by Dale x Garawi (42.0 %), whereas the lowest value was shown by Dale x S.186 (34.4 %). The commercial hybrid

‘Panar 888’ was significantly higher in leaf to stem ratio than most of the tested hybrids, showing a value of 42.8 %. Among male parents, Ankolib was the best in leaf to stem ratio and was significantly better than many hybrids. The male parents S.70 and S. 186 exhibited low values of leaf to stem ratio with the latter being the lowest in the whole material tested.

Stem diameter : Table 11 shows that the ranges for stem diameter of hybrids were 1.33 to 2.03 cm and 1.24 to 1.83 cm in the first and the second year, respectively, whereas the respective ranges of parents were 1.08 to 1.71 cm and 1.17 to 1.82 cm. The commercial hybrid ‘Panar 888’ was significantly the lowest in stem diameter than most of the tested hybrids. The highest value among hybrids for stem diameter was shown by E-35-1 x S.70 and Sugar Drip x Ankolib in the first and second year, respectively, whereas the lowest value was shown by Sugar Drip x Garawi and N 100 x Garawi in the first and second year, respectively. In both years, S.70 and E-35-1 expressed the highest stem diameter among male and female parents, respectively. Among male parent, Garawi exhibited the lowest value for stem diameter. With the exception of E-35-1, the female parents, were significantly lower in stem diameter than most of the hybrids.

Number of tillers per plant : The respective ranges for number of tillers per plant of hybrids in the first and the second year were 1.49 to 3.25 and 1.24 to 2.44, while those for parents were 1.00 to 2.89 and 0.90 to 2.16. The commercial hybrid 'Panar 888' significantly exceeded all entries in number of tillers per plant in the second year, averaging 3.30. However, in the first year, Panar 888 ranked second and was not significantly different from many hybrids. The highest values for tillering among hybrids were expressed by N 109 x Garawi and Dale x Garawi in the first and the second year, respectively. The lowest tillering hybrids were Sugar Drip x Ankolib and Dale x S. 186 in the second and the first year, respectively. Among male parents, Garawi was the highest in number of tillers per plant averaging 2.89 and 2.16, in the first and the second year, respectively. In the second year, Garawi was significantly higher than many hybrids in number of tillers per plant. The female parents expressed the lowest values for number of tillers per plant in the first year. In both years, the female parents N 109 and Blue Ribbon, kept the lowest value for number of tillers per plant. Among male parents, S. 186 was the lowest in number of tillers per plant in both years.

Regrowth : The respective ranges for regrowth of hybrids in the first and the second year were 199 to 574 gm/ m. row and 130 to 382 gm/ m. row, whereas those for parents were 20 to 449 gm/ m. row and 36 to 408 gm/ m. row. The highest values for regrowth were shown by the hybrid Dale x Garawi and the male parent Garawi in the first and the second year, respectively. The commercial hybrid 'Panar 888' was significantly higher in regrowth in both years, than most of the hybrids. Other hybrids with high values for regrowth included Hastings x Garawi and N 109 x Garawi in the first year and Sugar Drip x S.186 followed by Dale x S.186 in the second year. The hybrids N 100 x Ankolib and Blue Ribbon x S. 70 were the lowest in regrowth in the second and the first year, respectively. The female parents maintained the lowest value for regrowth in both years with N 109 showing the lowest values. The male parents S.70 and S. 186 were significantly lower in regrowth than most of the hybrids in the first year. The high coefficient of variability noticed for regrowth (Table 11) could be attributed to sampling error. However, the performance of most entries was within the expected trend for this character.

4.2 Combining ability study

Analysis of variance : Combined analysis of variance over years and locations to estimate combining ability effects was performed for six out of eight characters, namely, green matter yield (GMY), dry matter yield (DMY), number of days to flower, plant height, stem diameter and leaf to stem ratio. The other two characters (number of tillers per plant and regrowth) showed heterogeneity for error variance; hence their combining ability estimates are based on single analysis of variance.

Tables 12 and 13 show mean squares from the combined analysis of variance across years and locations for the six traits. The entries were partitioned into variations due to parents, hybrids, and hybrids vs parents (Table 12). Likewise, the hybrids were subdivided into variations due to lines (females), testers (males) and lines x testers (Table 13).

The entries and their sub-sources of variation (parents, hybrids, and parents vs hybrids) differed significantly ($p < 0.01$) for all of the six characters. The interaction of entries and hybrids with years was significant for all characters. The interaction of parents with years was significant for all characters with the exception of plant height. The interaction of entries, parents and hybrids with locations was not significant for the six characters. Higher order interactions with entries and their sub-sources of variation were also not significant for the six characters.

Table 13 shows that differences among lines, testers and line x tester were significant ($p < 0.01$) for the six characters. The interaction of lines with years was only significant ($p < 0.01$) for number of days to flower, plant height and stem diameter. The years x testers interaction was only significant ($p < 0.05$) for DMY and plant height. The interaction of lines x testers with years was significant (mostly $p < 0.01$) for GMY, number of days to flower, plant height stem diameter, leaf to stem ratio and DMY. The interactions of lines, testers and line x tester with location were not significant for the six characters. Likewise, higher order interactions for the six characters were not significant.

Table 14 shows mean squares from single line x tester analysis of variance for tillering and regrowth. For both characters, significant differences (mostly $p < 0.01$) were detected among hybrids, parents and parents vs hybrids in each year, at both locations. Differences among lines for both characters were mostly insignificant, whereas among testers, were mostly significant. The line x tester interaction for number of tillers per plant was consistently insignificant, whereas for regrowth, it was mostly significant.

4.2.1 General combining ability (GCA) effects

Table 15 shows general combining ability (GCA) effects from combined analysis of variance for GMY and DMY. Table 16 shows GCA effects from combined analysis of variance for number of days to flower, plant height, stem diameter and leaf to stem ratio. Tables 17 and 18 show GCA effects from single analysis of variance for tillering and regrowth, respectively.

Significant positive and negative GCA effects were expressed by some lines and testers for nearly all characters. The exceptions being plant height for both lines and testers and leaf to stem ratio for lines. More significant cases were displayed by testers compared to lines, with significant cases being more frequent for number of days to flower among both lines and testers.

Forage yield: Table 15 shows GCA effects for GMY and DMY along with their respective values for yield and yield rank. The highest significant ($p < 0.01$) positive GCA effect among lines was expressed by E-35-1, and among testers by S.70. Yield ranking indicates that both entries are among the top yielders in their groups. Positive, but insignificant, GCA effects were shown by the line Dale and the tester Ankolib.

Number of days to flower : For days to flower, where negative effects are desirable, Blue Ribbon from lines and S.186 from testers showed the highest significant ($p < 0.01$) negative GCA effects, followed by N 109 and Garawi from lines and testers respectively. Other significant negative effects were expressed by the lines Sugar Drip and N 100. Negative, but insignificant GCA effects were shown by the line Dale and the tester S.70. Positive significant ($p < 0.01$) GCA effects were expressed by the line E-35-1 and the tester Ankolib.

Plant height: No significant GCA effects were displayed by both lines and testers for plant height, however, E-35-1 and Dale from lines and S.70 from testers showed the highest positive effects. The line Blue Ribbon and the tester S.186 showed positive, but low GCA effects for plant height.

Stem diameter: Among lines, significant ($p < 0.01$) positive and significant ($p < 0.05$) negative GCA effects for stem diameter were expressed by E-35-1 and N 100, respectively. Among testers, significant ($p < 0.05$) positive and significant ($p < 0.05$) negative GCA effects were shown by Ankolib and Garawi, respectively.

Leaf to stem ratio: Garawi, among testers, gave the highest significant ($p < 0.01$) positive GCA effect for leaf to stem ratio, followed by Ankolib. No significant GCA effects were displayed by lines for leaf to stem ratio, however, N 100 showed the highest positive value, followed by Dale.

Tillering and Regrowth: Tables 17 and 18 show GCA effects for tillering and regrowth respectively. For both characters, the tester Garawi expressed the highest positive GCA effects, in most cases. On the other hand, the line Dale was the best for both characters in the year 2003, showing significant positive GCA effects at both locations.

4.2.2 Specific combining ability (SCA) effects

Table 15 shows SCA effects from combined analysis of variance for GMY and DMY. SCA effects for number of days to flower, plant height, stem diameter and leaf to stem ratio are presented in Table 16. SCA effects from single analysis of variance for tillering and regrowth are presented in Tables 17 and 18, respectively. Significant SCA effects ($p < 0.01$, $p < 0.05$) were displayed by some hybrids for all characters, with the exception of number of tillers per plant.

Forage yield: The highest significant ($p < 0.01$) positive SCA effect for GMY was shown by the hybrid Sugar Drip x Ankolib, followed by Blue Ribbon x Ankolib. Significant ($p < 0.05$) positive SCA effects were also shown by E-35-1 x Garawi, Dale x S.70, Hastings x S.70 and E.35-1 x S.186. Yield ranking indicated that hybrids with significant positive SCA effects were among the best yielders. However, the hybrid E-35-1 x S.70, which was the top yielder in the whole material, showed insignificant negative SCA effects although its parents expressed the highest significant positive GCA effects. In contrast, the parents of the hybrid with the highest SCA effect (Sugar Drip x Ankolib) showed insignificant and low GCA effects.

With respect to SCA effects for DMY, most of the hybrids, generally kept the same trend as in GMY. However, significant positive SCA effects were evident only for E-35-1 x Garawi and Dale x S.70. Relatively high, but insignificant positive SCA effects could be noted for the hybrid Sugar Drip x Ankolib.

Number of days to flower: The hybrids : E-35-1 x Ankolib, Dale x Ankolib, and Hastings x Garawi exhibited the highest significant ($p < 0.01$) negative SCA effects for number of days to flower, followed by Hastings x S.70, Hastings x S.186 and Blue Ribbon x Ankolib. The parents of the hybrid with the highest significant negative SCA effects (E-35-1 x

Ankolib) expressed the highest significant positive GCA effects. In contrast, many of the parents showing significant negative GCA effects failed to produce negative SCA effects in their respective hybrids.

Plant height: Although none of the parents displayed significant positive GCA effects for plant height, two of the hybrids viz., E-35-1 x S.186 and Sugar Drip x Ankolib expressed positive significant ($p < 0.01$) SCA effects for this character.

Stem diameter: Significant ($p < 0.01$) positive SCA effects for stem diameter were expressed by the hybrid Sugar Drip x Ankolib, whereas significant ($p < 0.01$) negative effects were shown by the hybrid E-35-1 x Ankolib. The parents of the latter hybrid expressed positive significant ($p < 0.01$) GCA effects for stem diameter.

Leaf to stem ratio: The highest significant positive ($p < 0.01$) SCA effects for leaf to stem ratio were shown by N 100 x Ankolib, followed by E-35-1 x Ankolib. The parents of the first hybrid showed positive GCA effects for leaf to stem ratio.

Tillering and Regrowth: Tables 17 and 18 show SCA effects for tillering and regrowth from single analysis of variance at Shambat and Islang respectively. For number of tillers per plant, no significant positive SCA effects were displayed. However, consistent positive, but insignificant SCA effects for number of tillers per plant were displayed by some hybrids. The major parents involved in these hybrids were Garawi from testers, Dale and Sugar Drip from lines. SCA effects for tillering shown by Hastings x Garawi, Dale x Garawi and N 100 x S.186 were relatively high, compared to other hybrids. It could be noted that, the tester Garawi, and the line Dale, are the only parents showing significant positive GCA effects for number of tillers per plant.

For regrowth, significant ($p < 0.05$) positive SCA effects were expressed by Sugar Drip x S.186 in the year 2003 at both locations, Dale x Garawi in the year 2002 at one location and N 100 x S.70 in the year 2003 at one location. The parents of the hybrid Dale x Garawi were the only ones that showed positive significant GCA effects for regrowth. Consistent, but insignificant positive SCA effects were displayed by some hybrids. Of these, E-35-1 x Ankolib was the most prominent.

4.2.3 Variance estimates for general and specific combining ability

GCA and SCA variance components: Table 19 shows variance components of general (σ^2 GCA) and specific (σ^2 SCA) combining abilities, their interactions with years and locations and the ratio of general to specific combining ability variance for GMY, DMY, number of days to flower, plant height, stem diameter and leaf to stem ratio. For all characters, variances of the main effects were significant ($p < 0.01$) and mostly higher in magnitude than the interaction effects.

However, interaction of SCA variance (σ^2 $SCA_{LxT \times Y}$) with years was the only exception, especially for plant height, where the interaction effect was sizeable. With the exception of number of days to flower and leaf to stem ratio, the variances of GCA for lines (σ^2 GCA_{Lines}) were higher than those for testers (σ^2 GCA_{Tester}). The interaction effects of σ^2 GCA_{Lines} with years for plant height, number of days to flower and stem diameter were higher than those of GCA variance for testers ($\sigma^2 GCA_{Tester}$). For all characters, higher order interactions of SCA variance (σ^2 $SCA_{LxT \ Y \times LO}$) were considerably low.

GCA/SCA Ratio: An estimate of the relative importance of general to specific effects could be shown by the ratio of general to specific combining ability variance (σ^2 GCA / σ^2 SCA). The ratio is above unity for all characters, except for plant height. The SCA variance for plant height was about more than three times greater than the sum of its GCA variance for line and tester. Number of days to flower showed the highest σ^2 GCA / σ^2 SCA ratio compared to other characters.

Table 20 shows variance components of general and specific combining ability from single analysis of variance for tillering and regrowth. The data for number of tillers per plant showed that GCA variances of testers were significant ($p < 0.01$) and higher than those of lines in the year 2002, at both locations. SCA variances for number of tillers per plant were considerably low than those of GCA variances. This was further indicated by the high σ^2 GCA / σ^2 SCA ratio that ranged from 4 to 41.

For regrowth, GCA variances of testers were consistently higher than those of lines. SCA variances were in most cases, markedly greater than GCA variances, with σ^2 GCA / σ^2 SCA ratio ranging from 0.5 to 1.4.

4.2.4 Contribution of lines, testers and line x testers to total variance

Table 21 shows that the contribution of lines was greater than that of testers for GMY, DMY, plant height and stem diameter. On the other hand, the contribution of testers was greater than that of lines for leaf to stem ratio. Equal contributions to the total variance by both lines and testers were noticed for number of days to flower. The contribution of either lines or testers was greater than that of lines x testers for all characters with the exception of plant height.

For number of tiller per plant, Table 22 shows that, in the year 2002, the contribution of testers was greater than that of lines at both locations, while the opposite was true in the year 2003.

For regrowth, the contribution of testers was consistently greater than that of lines. The contribution of line x tester for regrowth was higher than that for number of tillers per plant, especially in the year 2002 at Islang and 2003 at Shambat, where it exceeded the sum of both lines and testers.

4.3 Heterosis study

4.3.1 Heterosis in forage yield

Table 23 shows heterosis from combined data for green (GMY) and dry (DMY) matter yields, estimated as percentage over mid-parent (average heterosis), better parent (heterobeltiosis) and the commercial hybrid 'Panar 888' (standard heterosis).

Average heterosis: For GMY, positive and significant (mostly $p < 0.01$) values for average heterosis were displayed by most hybrids, with a mean average heterosis of 45.9 %, ranging from 4.91 % to 105.5 %. The hybrid N 100 x S.186 was the only exception, showing the lowest insignificant, but positive heterosis. The highest average heterosis was expressed by Sugar Drib x Ankolib (105.5 %), N 109 x Ankolib (98 %) and Blue Ribbon x Ankolib (91.6 %).

For DMY, the same situation holds in most cases, with a mean average heterosis of 45.6 %, ranging from 3.74 % to 114.9 %. However, the highest average heterosis was shown by the hybrid N 109 x Ankolib (114.9 %). Insignificant average heterosis for DMY was shown by Hastings x S.186 and N 100 x S.186. In most cases, the hybrids involving the male parent Ankolib displayed the highest average heterosis for forage yield. However, examination of the actual yield data (Tables 8 and 9) indicate that these were not necessarily the highest yielding hybrids.

Heterobeltiosis: Heterobeltiosis for GMY and DMY was positive and significant ($p < 0.01$, $p < 0.05$) for about half of the hybrids, averaging 25 % for both characters with a range of – 16.2 % to 92.3 % for GMY and – 13.4 % to 85.1 % for DMY. Negative and significant ($p < 0.01$) heterobeltiosis, for GMY, was displayed by the hybrid N 100 x S. 186. For both characters, the hybrids involving the tester Ankolib with the lines : Sugar Drip, N 109 and Blue Ribbon, showed the highest magnitude for heterobeltiosis.

Standard heterosis: Positive and significant (mostly $P < 0.01$) standard heterosis was displayed by six and four hybrids for GMY and DMY, respectively. Standard heterosis averaged – 3.67 % for GMY and –5.69 % for DMY with respective ranges of – 23.1 % to 24.3 % and – 25.8 % to 28.5 %. The hybrids involving the line E-35-1 with the testers: S.70, S.186

and Garawi, displayed the highest positive and significant ($p < 0.01$) standard heterosis, especially for GMY, with values ranging from 18.7 % to 28.5 %. The hybrid Dale x S.70 expressed positive significant standard heterosis for DMY (20.8%) and GMY (13.2 %). Other hybrids with significant ($p < 0.05$) positive standard heterosis for GMY included Hastings x S.70 and Sugar Drip x Ankolib.

4.3.2 Heterosis in yield-related traits

Heterosis from combined data for number of days to flower and plant height was shown in Table 24.

Number of days to flower: The mean of average heterosis for days to flower was – 2.23 %, ranging from – 9.84 % to 11.5 %. Negative heterosis was considered desirable for number of days to flower. Significant ($p < 0.01$, $p < 0.05$) negative values were expressed by more than half of the hybrids. Heterobeltiosis ranged from – 8.95 % to 30.6 % with a mean value of 5.09 %. Negative and significant ($p < 0.01$) heterobeltiosis was encountered for only three hybrids, all of them involving the tester S.70. Of these, Dale x S.70 was among the 5 top yielding hybrids, ranking third and fourth in dry and green matter yields, respectively (Table 15). Standard heterosis for days to flower ranged from – 21.2 % to 18.1

% with a mean value of – 8.79 %. The majority of hybrids displayed negative and significant (mostly $P < 0.01$) standard heterosis for number of days to flower. However, of these, Dale x S.70 was the only hybrid showing significant increase in forage yield over the commercial hybrid 'Panar 888' (Tables 8 and 9).

Plant height : The mean of average heterosis for plant height was 20.3 % ranging from 6.4 % to 56.1 %. All of the hybrids expressed positive significant (mostly $P < 0.01$) average heterosis for plant height. The highest average heterosis values were displayed by hybrids involving the line N109. Heterobeltiosis for plant height averaged 7.97 %, with a range of – 4.85 % to 28.3 %. Positive and significant (mostly $P < 0.01$) values over the better parent were noticed for 11 hybrids. None of the negative heterobeltiosis values for plant height were significant. Standard heterosis for plant height averaged 8.31 %, with a range of – 0.46 % to 16.6 %. The majority of hybrids deviate positively and significantly ($p < 0.01$, $p < 0.05$) from the commercial hybrid 'Panar 888'. It could be noted that the hybrid Dale x S.70 showed significant desirable heterosis over the commercial hybrid 'Panar 888' for forage yield, number of days to flower and plant height.

Stem diameter: Table 25 shows heterosis from combined analysis for stem diameter. Negative heterosis was considered desirable for stem diameter. However, none of the hybrids displayed significant negative values for stem diameter in all of the three types of heterosis. In contrast, significant (mostly $P < 0.01$) positive heterosis values were predominant, especially for standard heterosis and heterobeltiosis. Nonetheless, for average heterosis, low and insignificant negative values for stem diameter could be noted for two hybrids, namely, Dale x S.70 and N 100 x S.186. Mean heterosis values were: 11.28 % for average heterosis, 22.94 % for heterobeltiosis, and 40.43 % for standard heterosis, with respective ranges of – 5.56 % to 39.9 %, 3.03 % to 52.5 % and 21.8 % to 72.7 %.

Leaf to stem ratio: Table 25 shows heterosis from combined analysis for leaf to stem ratio. Mean heterosis values were -6.75 % for average heterosis, -14.3 % for heterobeltiosis and – 10.9 % for standard heterosis with respective ranges of – 18.2 % to 5.04 %, - 32.2 % to 4.22% and – 19.6 % to 2.34 %. Significant positive values were not evident for all hybrids in the three types of heterosis. Significant (mostly $P < 0.01$) negative heterosis values were predominant for heterobeltiosis and standard heterosis. However, the hybrids N100 x Ankolib and Dale x S.70 displayed positive, but low and insignificant average heterosis values for leaf to stem ratio.

Tillering : Tables 26 and 27 show heterosis from single analysis of variance for number of tillers per plant at Shambat (2002-2003) and Islang (2002-2003) respectively.

Average heterosis for number of tillers per plant was mostly positive in each year at both locations, however, few average heterosis values were significant ($p < 0.01$, $p < 0.05$). The highest mean of average heterosis for tillering (40.7 %) was recorded at Islang in the year 2002, with a range of – 1.37 % to 78.4 %, while the lowest mean (19.3 %) was encountered at Shambat in the year 2003, with a range of – 18.2 % to 78.7 %. The hybrids Dale x Garawi and Dale x Ankolib consistently showed significant ($p < 0.01$, $p < 0.05$) positive average heterosis in each year at both locations. Relatively high and significant positive ($P < 0.01$) average heterosis for tillering was displayed by the hybrids N 109 x Garawi and N 109 x Ankolib in the year 2002 at both locations.

The data for heterobeltiosis showed that very few positive significant values were displayed by hybrids with regard to number of tillers per plant. The majority of hybrids consistently showed moderate to low positive or negative values. Mean heterobeltiosis for tillering were moderate in the year 2002, amounting to 9.05 % at Shambat and 11.8 % at Islang with respective ranges of - 25.7 % to 54.2 % and – 20.9 % to 64.5 %. In the year 2003, mean heterobeltiosis values were very low at both locations, amounting to 0.88 % at Shambat and 2.8 % at Islang with respective ranges of – 29.5 % to 52.2 % and – 28.7 % to 77.9 %. The hybrids that showed positive and significant heterobeltiosis for number of tillers per plant included E-35-1 x S.70 at both locations in the year 2002, Sugar Drip x S.186 at Shambat and Dale x Ankolib at Islang in the year 2003.

Significant positive standard heterosis for number of tillers per plant was not encountered in all hybrids. High negative and significant (mostly $P < 0.01$) values were displayed by the majority of hybrids, especially in the year 2003 at both locations. Mean standard heterosis was consistently negative. In the year 2002, it averaged about – 28.8 % at Shambat and – 23.5 % at Islang with respective ranges of – 55.9 % to – 2.88 % and – 52.0 % to 4.33 %. In the year 2003, mean standard heterosis for tillering averaged about – 51.5 % at Shambat and – 46.6 % at Islang with respective ranges of – 64.6 % to – 29.7 % and – 60.4 % to 22.0%. The only case with positive standard heterosis for number of tillers per plant (4.33 %) was shown by the hybrid N 109 x Garawi at Islang, in the year 2002.

Regrowth: Tables 28 and 29 show heterosis for regrowth from single analysis of variance at Shambat (2002-2003) and Islang (2002-2003) respectively. Positive average heterosis values for regrowth were detected for the majority of hybrids. In the year 2002, around half of the hybrids showed significant ($p < 0.01$, $p < 0.05$) positive values at both locations, while in the year 2003, fewer positive significant ($p < 0.01$, $p < 0.05$) values could be observed especially at Shambat site. In the year 2002, the mean of heterosis for regrowth was 137.6 % at Shambat and 143.2 % at Islang with respective ranges of – 24.3 % to 379.5 % and – 29.7 % to 372.1 %. In the year 2003, the mean of average heterosis was 36.8 % at Shambat and 53.5 % at Islang with respective ranges of – 46.6 % to 182.1 % and – 42.8 % to 183.1 %. Five hybrids consistently displayed significant ($p < 0.01$, $p < 0.05$) positive values for average heterosis, namely, Hastings x S.70, N 109 x S.70, Dale x S. 186, N 100 x S.70 and Sugar Drip x S.186.

Significant positive heterobeltiosis for regrowth was displayed by few hybrids, two of them being consistently significant ($p < 0.01$, $p < 0.05$), namely, Hastings x S.70 and Sugar Drip x S.186. The mean of average heterobeltiosis for regrowth in the year 2002 was 62.5 % at Shambat and 66.3 % at Islang, with respective ranges of – 51.6 % to 217.7 % and – 56.1 % to 214.2%. In the year 2003, heterobeltiosis averaged very low compared to 2002, amounting to – 4.93 % at Shambat and 7.46 % at Islang with respective ranges of – 65.6 % to 115.7 % and – 42.8 % to 116.7 %.

Standard heterosis for regrowth was predominantly negative. However, in the year 2002, at both locations, positive insignificant values were displayed by three hybrids involving the tester Garawi with the lines : Hastings, N 109 and Dale. In the year 2002, standard heterosis averaged – 27.8 % at Shambat and – 34.0 % at Islang, with respective ranges of –

58.4 % to 31.9 % and – 59.1 % to 17 %. In the year 2003, standard heterosis averaged - 42.4% at Shambat and – 24.5 % at Islang with respective ranges of – 75.1 % to - 10.3 % and -54.1 % to 13.1 %.

4.4 Proximate analysis for forage quality traits

4.4.1 General performance

Table 30 shows mean squares from line x tester analysis of variance for the percentages of neutral detergent fiber (NDF), crude fiber (CF), crude protein (CP), Ash and ether extract (E.E.) of the 28 F1 hybrids and their parents, grown at Shambat in the year 2002. Significant ($p < 0.01$) differences were detected among hybrids for all characters. The parents differed significantly ($p < 0.01$) for the percentages of CF, CP and Ash and insignificantly for NDF and ether extract. Parents vs hybrids showed significant ($p < 0.01$) differences for all characters with the exception of E.E. percentage. For all characters, the lines and testers differed insignificantly, whereas the differences among lines x testers were significant ($p < 0.01$).

Table 31 shows percentages of NDF, CF, CP, Ash and E.E of the 28 F1 hybrids and their parents grown at Shambat in the year 2001.

Neutral detergent fiber (NDF): Low NDF percentages are preferable. The mean of NDF of the hybrids (61.6 %) was lower than that of parents (64.8 %) with respective ranges of 34.5 % to 75.5 % and 60 % to 69 %. The hybrids : Dale x S.70, Hastings x S.186 and Dale x Garawi were significantly ($p < 0.01$) the lowest in NDF percentages among the whole material tested with respective values of 34.5 % , 37.0 % and 45.5 %. The hybrids Blue Ribbon x S.186 and Blue Ribbon x Ankolib were significantly ($p < 0.05$) lower in NDF percentages compared to all parents other than the line E-35-1, with respective NDF percentages of 56 % and 56.5 %.

Crude fiber (CF): The mean of CF of the hybrids (34.9 %) was lower than that of the parents (36.7 %) with respective ranges of 27.5 % to 40 % and 32.5% to 42.5%. The hybrid N 100 x Garawi showed the lowest CF percentage in the whole material tested. The hybrids : N 109 x S.186, Hastings x S.70 and Sugar Drip x S.70 were significantly lower in CF percentage than most of the parents.

Crude protein (CP): The mean of CP percentage was slightly lower for the hybrids (5.57 %) than for the parents (5.98 %) with respective ranges of 3.17 % to 7.48 % and 3.65 % to 9.42 %. The highest CP percentage was shown by the tester Garawi (9.42 %). The hybrids : Dale x S.186, Hastings x S.70 and Hastings x Ankolib were the highest among hybrids in CP percentage, showing respective values of 7.48 %, 7.26 % and 7.18 %. Some of the parents were significantly ($p < 0.01$, $p < 0.05$) higher in CP percentage compared to some hybrids.

Ash: The hybrids averaged slightly higher in Ash (8.82 %) compared to their parents (8.15 %) with respective ranges of 7.16 % to 12.7 % and 6.19 % to 9.96 %. The hybrids : Sugar Drip x S.70, Blue Ribbon x Ankolib, E-35-1 x Ankolib and Blue Ribbon x Garawi were the highest in Ash percentage in the whole material tested, with respective values of 12.7 %, 11.2 %, 10.22 % and 10.20 %. The former hybrid was significantly ($p < 0.01$) higher in Ash percentage compared to all parents, while the other three showed significant ($p < 0.05$) increase over most of the parents.

Ether extract (E.E.): The hybrids were slightly lower in E.E. averaging 1.32 % compared to 1.37 % for parents, with respective ranges of 0.79 % to 2.43 % and 0.82 % to 1.62 %. The hybrids : Sugar Drip x Garawi, N 100 x Ankolib and

Blue Ribbon x S.70 were the highest in E.E. percentage in the whole material tested, with respective values of 2.43 %, 2.0 % and 2.0 %. The former hybrid was significantly ($p < 0.01$) higher in E.E. percentage, compared to all parents.

4.4.2 Combining ability in forage quality traits

Table 32 shows the results of general (GCA) and specific (SCA) combining ability effects for the characters studied.

Neutral detergent fiber (NDF): Significant negative GCA effects for NDF were expressed by the lines Dale ($p < 0.01$) and Hastings ($p < 0.05$). Significant ($p < 0.05$) negative GCA effects for NDF percentage were displayed by the testers S.70 and S.186. Among hybrids, significant ($p < 0.01$) negative SCA effects were displayed by the hybrids : Hastings x S.186, Dale x S.70, Dale x Garawi and Blue Ribbon x Ankolib. It could be noticed from Table 31 that these hybrids were among the lowest ones in NDF percentages. It could also be noted that the line Dale was involved in two of these hybrids.

Crude fiber (CF): No significant negative GCA effects for CF percentage were shown by the parents. However, Dale, N 100, Sugar Drip among lines and S.70 and Garawi among testers, showed negative GCA values. Significant negative (mostly $p < 0.05$) SCA effects for CF percentage were expressed by four hybrids, namely, E-35-1 x S.70, Hastings x S.70, N 109 x S.186 and N100 x Garawi. Some of the parents showing negative GCA effects were involved in these hybrids, especially the line N 100 and the tester Garawi. These two parents displayed the highest negative GCA effects for CF percentage among their groups.

Crude protein (CP): Significant ($p < 0.05$) positive GCA effect for CP percentage was displayed by the line Hastings, whereas among testers, no significant positive GCA effects were displayed. No significant positive SCA effects for CP percentage were expressed by any of the hybrids. Most of the hybrids involving Hastings (the only parent with significant positive GCA effect) showed negative SCA effects for CP.

Ash: Positive significant ($p < 0.01$) GCA effects for Ash percentage were only evident for Blue Ribbon and Sugar Drip among lines and Ankolib among testers. Significant positive SCA effects among hybrids were only displayed by Sugar Drip x S.70 ($p < 0.01$) and Dale x S.186 ($p < 0.05$).

Ether extract (E.E.): No significant GCA effects were expressed by lines and testers for ether extract percentage, however, the highest positive GCA values were shown by the tester Garawi and the line Sugar Drip. Positive significant SCA effects for E.E. percentage were displayed by Blue Ribbon x S. 70, Sugar Drip x Garawi and N 100 x Ankolib.

4.4.3 Heterosis in forage quality traits

Tables 33 and 34 show the results of average heterosis and heterobeltiosis for the characters studied.

Neutral detergent fiber (NDF): Average heterosis and heterobeltiosis values for NDF percentage were negative for the majority of the hybrids, with some showing significant ($p < 0.01$, $p < 0.05$) negative values. The mean heterosis was negative, amounting to – 5.19 % for average heterosis and – 3.11 % for heterobeltiosis, with respective ranges of – 47.3 % to 22.3 % and – 46 % to 25.8 %. The hybrids : Dale x S.70, Hastings x S.186 and Dale x Garawi exhibited the highest negative and significant ($p < 0.01$) values for average heterosis and heterobeltiosis as well. Two of these hybrids, were among the best performing with respect to NDF percentage (Table 31) and SCA effects (Table 32).

Crude fiber (CF): The values of average heterosis and heterobeltiosis for CF percentage were negative for more than half of the hybrids, with some showing significant ($p < 0.01$, $p < 0.05$) negative values. The mean heterosis was negative, amounting to – 5.57 % for average heterosis and – 1.47 % for heterobeltiosis, with respective ranges of – 27.6 % to 9.09 % and – 17.9% to 13.9 %. The hybrids involving the tester Garawi with the lines : N100, N 109, Dale and Sugar Drip showed the highest negative and significant ($p < 0.01$) average heterosis for CF percentage. On the other hand the hybrids

: N 100 x Garawi, N 109 x S.186 and Sugar Drip x S.70 showed the highest negative significant ($p < 0.01$) heterobeltiosis for CF percentage. Table 31 indicates that some of these hybrids were among the best performing with respect to CF percentage.

Crude protein (CP): Average heterosis and heterobeltiosis values for CP percentage were negative in most cases. However, few hybrids displayed positive significant ($p < 0.01$, $p < 0.05$) values. The mean of heterosis was negative, amounting to – 2.9 % for average heterosis and – 16.1 % for heterobeltiosis, with respective ranges of – 53.5 % to 79.2 % and – 64.4% to 68.5 %. The hybrids Dale x S.186 and Hastings x Ankolib showed the highest positive and significant ($p < 0.01$) average heterosis and heterobeltiosis. Dale x S.186 was also the best performing hybrid with respect to CP percentage (Table 31) and SCA effects (Table 32). Other hybrids showing positive significant ($p < 0.05$) heterosis include those involving the line Hastings with the testers: S.186 (for both types of heterosis) and S.70 (for average heterosis). The line Hastings, which was involved in most hybrids showing significant positive heterosis, was the only one among parents to display significant positive GCA effects for CP percentage.

Ash : For Ash percentage, average heterosis was positive for the majority of the hybrids, whereas less cases with positive

Experiment	Source of	d.f.	Green	Dry matter	Days to	Plant ht	Stem	Leaf/stem	No. of	Regrowth

values were noted for heterobeltiosis. The mean heterosis was 7.61 % for average heterosis and – 1.69 % for heterobeltiosis, with respective ranges of – 10.7 % to 54.3 % and – 23 % to 40.3 %. Positive significant values were observed for 6 and 3 hybrids for average heterosis and heterobeltiosis, respectively. The highest positive and significant ($p < 0.01$) values for both types of heterosis were displayed by the hybrids : Sugar Drip x S.70, Dale x S.186, and Blue Ribbon x Ankolib. Two of these hybrids were among the best in Ash percentage (Table 31) and SCA effects (Table 32).

Ether Extract (E.E): Most of the average heterosis and heterobeltiosis values for E.E. percentage were negative. The mean of heterosis was negative, amounting to – 3.25 % for average heterosis and – 12.6 % for heterobeltiosis with respective ranges of – 49.7 % to 73.6 % and – 50.6 % to 65.3 %. However, two hybrids displayed positive significant ($p < 0.01$) average heterosis and heterobeltiosis, namely, Sugar Drip x Garawi and N 100 x Ankolib. Both hybrids were among the best performing, with respect to E.E percentage (Tables 31) and SCA Effects (Table 32).

Table 1. Mean squares from single analysis of variance for different characters in forage sorghum of the hybrids, their parents and the hybrid check, grown in 2 years at locations

Location	Year										
Shambat	2002	Block	2	109.7 NS	4.431**	87.56 **	19179.1**	0.052 NS	205.0 **	10.51**	84111.4 **
		Entry	39	240.9 **	3.932 **	169.6 **	2406.8 **	0.149 **	34.91 **	1.153 **	57643.0 **
Shambat	2003	Block	2	48.85 NS	0.499 NS	53.58 **	814.86 *	0.025 NS	3.267 NS	1.157 **	8442.5 NS
		Entry	39	227.20 **	4.475 **	202.78 **	2561.0 **	0.104 **	52.45 **	0.615 **	31476.7 **
Islang	2002	Block	2	74.68 NS	3.677 **	72.48 **	17927.5 **	0.023 NS	212.3 **	9.273 **	41506.3 **
		Entry	39	253.21 **	4.094 **	163.31 **	2481.2 **	0.176 **	65.60 **	1.030 **	52367.3 **
Islang	2003	Block	2	22.77 NS	0.083 NS	46.66 **	799.30 *	0.006 NS	45.44 *	0.499 *	21667.6 **
		Entry	39	199.85 **	3.874 **	214.40 **	2071.2 **	0.085 **	56.48 **	0.516 **	22774.7 **

*, **, = significant at 0.05 and 0.01 probability level respectively

NS = non-significant at 0.05 probability level

Table 2. Mean squares from combined analysis over years (2002-2003) and locations (Shambat, Islang) for 5 characters in forage sorghum of the hybrids, their parents and the check hybrid

Source of variation	d.f.	Mean squares				
		Green matter yield (t/ha)	Dry matter yield (t/ha)	Days to flower	Plant ht (cm)	Leaf/stem ratio (percentage)
Locations (Lo)	1	1052.2**	15.7**	220.9**	19053.7**	1646.2**
Years (Yr)	1	459.3**	1.61 ^{NS}	2169.2**	1634.7*	204.0**
Blocks in Lo x Yr	8	64.0*	2.17**	65.1**	9680.2**	116.5**
Lo x Yr	1	17.0 ^{NS}	0.737^{NS}	47.9**	4624.0**	21.7 ^{NS}
Entry	39	843.9**	15.0**	718.2**	8660.7**	182.7**
Yr x Entry	39	69.8**	1.20**	29.7**	746.0**	19.2*
Lo x Entry	39	3.86 ^{NS}	0.053^{NS}	0.985 ^{NS}	60.2 ^{NS}	3.09 ^{NS}
Yr x Lo x Entry	39	3.59 ^{NS}	0.072^{NS}	1.18 ^{NS}	53.4 ^{NS}	4.38 ^{NS}
Error	312	30.6	0.651	6.35	255.4	12.0

*, **, = significant at 0.05 and 0.01 probability level respectively.
N.S. = non-significant at o.o5 probability level.

Table 3. Mean squares from combined analysis over locations (Shambat, Islang) for 3 characters in forage sorghum of the hybrids, their parents, and the check hybrid, grown in 2002 and 2003

Source of Variation	d.f.	2002 Mean squares			2003 Mean squares		
		No. of tillers/ plant	Stem diam (cm)	Regrowth (g/m row)	No. of tillers/ plant	Stem diam (cm)	Regrowth (g/m row)
Locations (Lo)	1	2.210*	0.944**	8833.1^{NS}	0.027 ^{NS}	0.843**	7392.6 ^{NS}
Blocks in Lo	4	9.891**	0.038**	62808.9 **	0.828**	0.016 ^{NS}	15055.1**
Entry	39	2.166**	0.317**	108782.8**	1.122**	0.187**	52845.4**
Lo x Entry	39	0.017 ^{NS}	0.007 ^{NS}	1227.6 ^{NS}	0.009 ^{NS}	0.003 ^{NS}	1406.0 ^{NS}
Error	156	0.265	0.018	10163.3	0.134	0.015	4320.0

*, **, = significant at 0.05 and 0.01 probability level respectively.
N.S. = non-significant at o.o5 probability level.

Table 4. Performance of forage sorghum hybrids, their parents and a check hybrid for green (GMY), dry (DMY) matter yields and yield-related traits (Shambat, 2002)

Entry		GMY (t/ha)	DMY (t/ha)	Days to flower	Plant ht (cm)	Stem diam (cm)	No. of tillers/ plant	Leaf/stem ratio (percentage)	Regrowth (g/m row)
	Hybrids								
1	E-35-1 X S.70	49.5	6.34	78.3	246	2.04	2.73	37.2	252
2	E-35-1 X S.186	51.0	6.40	72.7	265	1.97	1.93	35.3	221
3	E-35-1 X Garawi	51.7	6.39	74.0	257	1.82	3.00	37.7	214
4	E-35-1 X Ankolib	44.4	6.05	78.3	232	1.86	2.67	41.3	292
5	Hastings X S.70	46.6	5.39	63.7	233	1.70	1.80	35.3	347
6	Hastings X S.186	42.1	4.64	58.3	257	1.64	2.13	35.4	316
7	Hastings X Garawi	39.0	4.07	59.3	232	1.51	3.10	39.3	525
8	Hastings X Ankolib	40.1	4.95	79.0	218	1.94	2.43	36.3	188
9	B.Ribbon X S.70	42.6	4.69	59.3	251	1.60	1.93	35.5	205
10	B.Ribbon X S.186	37.9	4.05	57.0	246	1.63	2.30	34.2	392
11	B.Ribbon X Garawi	32.2	3.84	59.0	240	1.50	2.23	41.2	297
12	B.Ribbon X Ankolib	51.8	6.38	70.7	264	1.92	2.63	35.4	289
13	N 109 X S.70	38.2	5.19	61.3	240	1.67	2.27	35.8	314
14	N 109 X S.186	34.6	4.67	58.0	237	1.45	2.03	34.7	374
15	N 109 X Garawi	37.6	4.26	57.0	241	1.48	3.37	40.1	523
16	N 109 X Ankolib	47.5	5.61	67.0	241	1.73	3.10	40.7	322
17	Dale X S.70	48.7	6.23	67.7	240	1.53	2.30	36.8	262
18	Dale X S.186	41.3	4.65	59.3	256	1.54	1.53	33.6	307
19	Dale X Garawi	35.1	4.26	62.0	234	1.58	3.23	40.8	596
20	Dale X Ankolib	39.7	4.61	70.7	238	1.68	2.80	39.2	208
21	N 100 X S.70	48.0	6.21	62.3	245	1.73	2.23	34.8	316
22	N 100 X S.186	30.7	3.62	57.7	218	1.39	2.40	40.1	405
23	N 100 X Garawi	40.2	4.60	58.3	241	1.57	2.83	38.6	365
24	N 100 X Ankolib	41.5	4.74	75.7	248	1.51	2.73	39.5	261
25	Sugar Drip X S.70	40.3	5.05	63.3	234	1.70	2.37	36.0	272
26	Sugar Drip X S.186	34.4	4.00	58.3	237	1.57	1.97	37.1	432
27	Sugar Drip X Garawi	31.9	3.93	58.7	230	1.34	2.67	40.3	384
28	Sugar Drip X Ankolib	44.7	5.22	68.3	223	1.94	2.47	38.0	259
	Parents								
29	E-35-1 ♀	29.4	3.62	84.3	167	1.62	1.57	44.8	123
30	Hastings ‘’	24.9	2.96	65.7	198	1.35	1.37	40.7	72
31	Blue Ribbon ‘’	20.7	2.36	58.0	196	1.29	1.07	41.1	44
32	N 109 ‘’	17.2	2.17	62.0	121	1.16	1.10	50.5	20
33	Dale ‘’	21.2	2.83	76.7	197	1.35	1.30	40.6	61
34	N 100 ‘’	23.5	3.14	65.7	190	1.36	1.50	39.0	100
35	Sugar Drip ‘’	25.1	3.03	69.7	195	1.36	1.83	41.6	67
36	S.70 ♂	38.1	4.84	71.3	230	1.77	1.77	35.0	142
37	S.186 ‘’	34.4	3.99	57.0	234	1.62	1.93	31.6	136
38	Garawi ‘’	32.9	3.87	58.3	234	1.36	3.00	38.7	442
39	Ankolib ‘’	29.2	3.40	65.0	185	1.58	2.50	39.6	257
	Check								
40	Panar 888	39.8	5.37	68.3	214	1.06	3.47	40.7	452
	Mean	37.5	4.54	65.4	228	1.59	2.29	38.4	276
	S.E.±	3.74	0.49	1.80	10.4	0.08	0.32	2.1	63.7
	LSD (0.05)	10.5	1.37	5.05	29.2	0.22	0.89	5.92	179.4
	C.V %	17.3	18.5	4.8	7.9	8.5	23.9	9.5	39.9

Table 5. Performance of forage sorghum hybrids, their parents and a check hybrid for green (GMY), dry (DMY) matter yields and yield-related traits (Islang, 2002)

Table 5. Performance of forage sorghum hybrids, their parents and a check hybrid for green (GMY), dry (DMY) matter yields and yield-related traits (Islang, 2002)

Entry		GMY (t/ha)	DMY (t/ha)	Days to flower	Plant ht (cm)	Stem diam (cm)	No. of tillers/ plant	Leaf/stem ratio (percentage)	Regrowth (g/m row)
	Hybrids								
1	E-35-1 X S.70	49.1	6.37	76.7	243	2.03	2.73	37.4	253
2	E-35-1 X S.186	48.5	6.09	71.3	260	1.88	1.85	37.1	212
3	E-35-1 X Garawi	48.2	5.95	72.5	252	1.70	2.79	40.3	200
4	E-35-1 X Ankolib	42.8	5.72	76.6	230	1.80	2.57	42.8	302
5	Hastings X S.70	44.1	5.10	62.3	228	1.60	1.70	37.4	327
6	Hastings X S.186	35.5	3.91	56.3	248	1.38	1.80	40.6	266
7	Hastings X Garawi	42.4	4.13	57.7	226	1.40	2.87	40.4	486
8	Hastings X Ankolib	37.6	4.63	76.8	213	1.81	2.25	39.0	268
9	B.Ribbon X S.70	40.0	4.70	57.9	245	1.50	1.81	37.9	193
10	B.Ribbon X S.186	35.3	3.77	55.4	238	1.52	2.15	36.8	364
11	B.Ribbon X Garawi	31.7	3.77	57.5	232	1.47	2.19	41.9	292
12	B.Ribbon X Ankolib	49.3	6.07	69.3	259	1.82	2.50	37.3	371
13	N 109 X S.70	35.7	4.76	59.6	233	1.55	2.12	38.5	292
14	N 109 X S.186	32.0	4.33	56.2	230	1.34	1.87	36.8	347
15	N 109 X Garawi	35.1	4.41	55.4	234	1.39	3.13	43.1	488
16	N 109 X Ankolib	41.9	5.27	64.6	232	1.52	2.72	44.5	290
17	Dale X S.70	46.1	5.91	66.3	235	1.45	2.18	38.9	248
18	Dale X S.186	38.7	4.77	57.9	249	1.44	1.44	35.9	288
19	Dale X Garawi	32.5	3.94	60.2	228	1.47	2.99	44.1	552
20	Dale X Ankolib	37.1	4.31	68.9	232	1.63	2.62	42.0	237
21	N 100 X S.70	45.4	5.75	61.0	240	1.64	2.11	36.7	299
22	N 100 X S.186	28.1	3.32	55.8	211	1.27	2.20	43.5	371
23	N 100 X Garawi	34.7	3.96	56.2	235	1.34	2.43	42.2	313
24	N 100 X Ankolib	36.9	4.22	73.4	242	1.34	2.44	43.9	210
25	Sugar Drip X S.70	37.7	4.73	61.6	227	1.58	2.18	38.9	253
26	Sugar Drip X S.186	31.9	4.13	56.6	230	1.45	1.82	40.1	399
27	Sugar Drip X Garawi	29.3	3.61	56.8	222	1.23	2.45	44.0	353
28	Sugar Drip X Ankolib	42.2	4.92	66.7	218	1.83	2.33	40.3	245
	Parents								
29	E-35-1 ♀	26.9	3.30	81.4	161	1.47	1.42	51.3	113
30	Hastings ‘’	22.3	2.65	62.9	190	1.20	1.22	44.4	64
31	Blue Ribbon ‘’	18.1	2.07	55.2	187	1.13	0.93	46.1	46
32	N 109 ‘’	14.6	1.84	58.4	114	0.99	0.93	56.1	20
33	Dale ‘’	18.7	2.49	72.8	188	1.18	1.13	44.1	53
34	N 100 ‘’	20.9	2.80	62.8	182	1.21	1.33	43.0	89
35	Sugar Drip ‘’	18.5	2.24	66.5	187	1.01	1.37	53.3	62
36	S.70 ♂	35.6	4.51	69.4	224	1.65	1.66	37.2	132
37	S.186 ‘’	35.4	4.30	55.5	227	1.51	1.79	33.9	127
38	Garawi ‘’	30.3	3.57	56.5	227	1.26	2.77	42.3	456
39	Ankolib ‘’	24.7	2.86	62.7	179	1.34	2.12	46.1	217
	Check								
40	Panar 888	40.6	5.14	66.3	213	1.09	3.00	45.4	472
	Mean	34.9	4.26	63.4	221	1.46	2.10	41.6	264
	S.E.±	3.59	0.44	1.72	10.3	0.08	0.28	2.19	52.1

LSD (0.05)	10.1	1.25	4.84	28.0	0.22	0.78	6.16	146.8
C.V %	17.8	18.0	4.7	8.0	9.4	22.9	9.1	34.0

Table 6. Performance of forage sorghum hybrids, their parents and a check hybrid for green (GMY), dry (DMY) matter yields and yield-related traits (Shambat, 2003)

Entry		GMY (t/ha)	DMY (t/ha)	Days to flower	Plant ht (cm)	Stem diam (cm)	No. of tillers/ plant	Leaf/stem ratio (percentage)	Regrowth (g/m row)
	Hybrids								
1	E-35-1 X S.70	52.8	7.26	71.3	250	1.82	1.33	32.5	304
2	E-35-1 X S.186	50.0	6.36	68.0	253	1.72	1.77	35.1	165
3	E-35-1 X Garawi	49.4	7.32	68.3	253	1.60	1.87	34.8	234
4	E-35-1 X Ankolib	45.4	6.16	77.3	232	1.64	1.50	38.2	215
5	Hastings X S.70	45.4	5.82	56.7	267	1.72	1.43	32.3	297
6	Hastings X S.186	31.4	3.90	54.3	242	1.62	1.50	32.3	215
7	Hastings X Garawi	38.6	4.47	54.3	241	1.60	1.90	35.9	326
8	Hastings X Ankolib	33.3	4.46	81.7	222	1.64	1.27	37.5	214
9	B.Ribbon X S.70	38.3	5.13	54.3	239	1.53	1.37	34.5	227
10	B.Ribbon X S.186	36.1	4.65	50.3	241	1.32	1.47	33.0	192
11	B.Ribbon X Garawi	38.3	4.85	53.3	250	1.39	1.93	35.8	291
12	B.Ribbon X Ankolib	38.0	4.17	56.7	229	1.58	1.73	33.4	133
13	N 109 X S.70	40.5	5.56	55.0	253	1.42	1.80	33.5	254
14	N 109 X S.186	38.0	4.92	51.3	230	1.44	1.30	35.6	221
15	N 109 X Garawi	32.1	3.90	53.7	239	1.40	1.90	38.2	317
16	N 109 X Ankolib	36.4	5.50	64.0	237	1.60	1.57	33.9	134
17	Dale X S.70	45.1	6.64	61.0	259	1.47	1.87	36.3	275
18	Dale X S.186	39.2	5.50	55.7	248	1.54	1.90	32.0	375
19	Dale X Garawi	35.2	4.81	57.3	249	1.44	2.44	39.0	332
20	Dale X Ankolib	39.5	4.76	63.3	241	1.56	2.13	39.0	331
21	N 100 X S.70	38.6	5.46	55.7	250	1.53	1.47	36.0	371
22	N 100 X S.186	34.5	4.52	52.7	230	1.44	1.77	30.9	241
23	N 100 X Garawi	30.6	4.23	54.7	238	1.29	1.53	37.0	241
24	N 100 X Ankolib	34.3	4.52	69.0	219	1.58	1.70	43.1	109
25	Sugar Drip X S.70	38.3	4.87	58.3	240	1.54	1.63	37.0	246
26	Sugar Drip X S.186	41.0	5.48	53.3	236	1.54	2.10	35.7	392
27	Sugar Drip X Garawi	30.6	4.15	54.3	239	1.47	1.70	35.9	210
28	Sugar Drip X Ankolib	48.4	5.63	65.3	272	1.90	1.23	34.4	182
	Parents								
29	E-35-1 ♀	35.5	5.39	82.7	188	1.76	1.43	41.7	129
30	Hastings ‘’	22.2	2.81	59.0	197	1.32	1.03	41.5	107
31	Blue Ribbon ‘’	25.3	2.90	54.0	212	1.23	1.00	40.9	66
32	N 109 ‘’	17.9	2.25	55.3	121	1.25	0.90	52.1	37
33	Dale ‘’	21.3	3.05	68.0	193	1.19	1.23	36.0	127
34	N 100 ‘’	22.8	3.15	59.0	179	1.37	1.57	39.3	91
35	Sugar Drip ‘’	18.8	2.53	62.3	181	1.25	0.97	41.6	101
36	S.70 ♂	42.6	5.45	64.7	252	1.91	1.57	29.9	172
37	S.186 ‘’	41.4	5.08	53.3	235	1.63	1.38	30.6	266
38	Garawi ‘’	26.2	3.51	55.3	243	1.22	2.17	37.8	463
39	Ankolib ‘’	23.1	3.04	68.0	179	1.44	1.63	41.6	317
	Check								
40	Panar 888	40.6	5.21	69.0	226	1.21	3.47	39.4	437
	Mean	35.9	4.74	60.6	230	1.50	1.64	36.6	234
	S.E.±	3.03	0.51	1.02	7.94	0.07	0.21	1.65	43.1
	LSD (0.05)	8.52	1.44	2.86	22.4	0.19	0.61	4.65	121.4
	C.V %	14.6	18.6	2.9	5.9	7.9	22.7	7.8	31.9

Table 7. Performance of forage sorghum hybrids, their parents and a check hybrid for green (GMY), dry (DMY) matter yields and yield-related traits (Islang, 2003)

Table 7. Performance of forage sorghum hybrids, their parents and a check hybrid for green (GMY), dry (DMY) matter yields and yield-related traits (Islang, 2003)

Entry			GMY (t/ha)	DMY (t/ha)	Days to flower	Plant ht (cm)	Stem diam (cm)	No. of tillers/ plant	Leaf/stem ratio (percentage)	Regrowth (g/m row)
	Hybrids									
1	E-35-1	X S.70	49.0	6.75	70.7	234	1.72	1.34	35.6	287
2	E-35-1	X S.186	45.9	5.82	68.0	234	1.62	1.77	38.2	157
3	E-35-1	X Garawi	44.0	6.51	66.6	226	1.44	1.85	39.2	239
4	E-35-1	X Ankolib	40.5	5.58	78.1	218	1.49	1.50	43.1	204
5	Hastings	X S.70	42.5	5.43	56.8	253	1.55	1.44	36.3	282
6	Hastings	X S.186	28.2	3.50	53.5	217	1.50	1.50	36.3	202
7	Hastings	X Garawi	36.9	4.23	53.7	233	1.51	1.90	38.3	321
8	Hastings	X Ankolib	31.6	4.24	81.6	220	1.55	1.27	40.2	203
9	B.Ribbon	X S.70	34.2	4.60	53.2	213	1.38	1.37	38.9	219
10	B.Ribbon	X S.186	32.3	4.17	50.5	223	1.19	1.47	37.1	181
11	B.Ribbon	X Garawi	34.2	4.34	51.4	224	1.26	1.93	40.2	278
12	B.Ribbon	X Ankolib	34.0	3.73	55.4	204	1.43	1.77	37.6	158
13	N 109	X S.70	36.2	4.97	53.3	227	1.29	1.80	37.7	239
14	N 109	X S.186	34.0	4.39	50.7	212	1.31	1.31	40.1	278
15	N 109	X Garawi	28.8	3.48	52.6	214	1.27	1.90	43.0	303
16	N 109	X Ankolib	32.6	4.92	63.5	216	1.48	1.57	38.1	158
17	Dale	X S.70	42.5	6.33	61.3	247	1.37	1.87	39.2	264
18	Dale	X S.186	35.1	4.91	54.7	222	1.43	1.90	36.0	354
19	Dale	X Garawi	31.5	4.30	56.1	223	1.29	2.44	44.0	319
20	Dale	X Ankolib	35.3	4.26	61.8	216	1.44	2.13	43.9	313
21	N 100	X S.70	34.5	4.88	54.6	231	1.38	1.47	40.5	351
22	N 100	X S.186	30.9	4.06	52.7	206	1.34	1.77	34.8	224
23	N 100	X Garawi	27.4	3.80	53.4	214	1.20	1.54	41.7	236
24	N 100	X Ankolib	30.7	4.06	67.4	195	1.43	1.70	48.5	151
25	Sugar Drip	X S.70	34.2	4.36	56.7	215	1.39	1.63	41.7	238
26	Sugar Drip	X S.186	36.7	4.90	52.7	211	1.39	1.76	40.2	372
27	Sugar Drip	X Garawi	27.5	3.75	53.5	214	1.33	1.70	40.7	259
28	Sugar Drip	X Ankolib	45.5	5.27	65.5	255	1.77	1.24	37.4	170
	Parents									
29	E-35-1	♀	31.8	4.83	81.8	168	1.59	1.42	46.6	122
30	Hastings	‘’	20.2	2.55	57.0	178	1.22	1.02	47.0	100
31	Blue Ribbon	‘’	22.8	2.62	53.5	194	1.13	0.99	46.1	60
32	N 109	‘’	16.3	2.05	53.6	110	1.21	0.89	56.2	36
33	Dale	‘’	19.3	2.77	66.5	174	1.14	1.22	40.5	118
34	N 100	‘’	21.1	2.92	59.5	166	1.33	1.55	42.9	86
35	Sugar Drip	‘’	19.5	2.63	65.0	194	1.27	0.96	43.2	97
36	S.70	♂	38.0	4.86	63.4	226	1.73	1.57	35.6	162
37	S.186	‘’	37.0	4.54	51.7	210	1.48	1.38	34.4	227
38	Garawi	‘’	23.7	3.18	54.5	219	1.12	2.16	41.5	352
39	Ankolib	‘’	16.9	2.21	69.7	179	1.38	1.47	42.2	264
	Check									
40	Panar 888		40.0	5.08	66.7	217	1.05	3.13	45.5	329
	Mean		32.6	4.30	59.8	211	1.39	1.62	40.8	223

Table 8. Green matter yield (GMY) of forage sorghum hybrids (1-28), their parents, and a hybrid check (Panar 888) averaged over years (2002-2003) and locations (Shambat, Islang)

S.E.±	2.20	0.42	1.12	8.02	0.07	0.21	2.0	31.9
LSD (0.05)	6.19	1.18	3.16	22.6	0.20	0.58	5.64	89.9
C.V %	11.7	16.9	3.2	6.5	8.9	22.2	8.5	24.8

Entry	Name	GMY (t/ha)#	
1	E-35-1 x S.70	50.10	A
2	E-35-1 x S.186	48.80	AB
3	E-35-1 x Garawi	48.30	AB
17	Dale x S.70	45.60	ABC
28	Sugar Drip x Ankolib	45.20	ABCD
5	Hastings x s.70	44.60	BCDE
4	E-35-1 x Ankolib	43.30	CDEF
12	Blue Ribbon x Ankolib	43.30	CDEF
21	N 100 x S.70	41.60	CDEFG
40	Panar 888 (check)	40.30	DEFGH
16	N 109 x Ankolib	39.60	EFGHI
7	Hastings x Garawi	39.20	FGHIJ
9	Blue Ribbon x S.70	38.80	FGHIJK
36	S.70 (male parent)	38.60	FGHIJKL
18	Dale x S. 186	38.60	FGHIJKL
20	Dale x Ankolib	37.90	GHIJKL
13	N 109 x S.70	37.70	GHIJKL
25	Sugar Drip x S.70	37.60	GHIJKL
37	S.186 (male parent)	37.00	GHIJKL
26	Sugar Drip x S.186	36.00	HIJKLM
24	N 100 x Ankolib	35.80	HIJKLM
8	Hastings x Ankolib	35.60	HIJKLM
10	Blue Ribbon x S.186	35.40	HIJKLM
14	N 109 x S.186	34.60	IJKLMN
6	Hastings x S.186	34.30	IJKLMN
11	Blue Ribbon x Garawi	34.10	JKLMN
19	Dale x Garawi	33.60	KLMN
15	N 109 x Garawi	33.40	KLMN
23	N 100 x Garawi	33.20	LMNO
22	N 100 x S.186	31.00	MNO
29	E-35-1 (female parent)	30.90	MNO
27	Sugar Drip x Garawi	29.80	NO
38	Garawi (male parent)	28.30	O
39	Ankolib (male parent)	23.50	P
30	Hastings (female parent)	22.40	P
34	N 100 (female parent)	22.10	P
31	Blue Ribbon (female parent)	21.70	P
35	Sugar Drip (female parent)	20.50	PQ
33	Dale (female parent)	20.10	PQ
32	N 109 (female parent)	16.50	Q
	Mean	35.2	
	S.E.±	1.60	
	Range: Hybrids	29.8-50.1	
	Range: Parents	16.5-38.6	
	LSD(0.05)	4.44	
	LSD(0.01)	5.79	
	CV (%)	15.7	

#: Means with letter in common are not significantly different at 0.05 Probability level according to Duncan's multiple range test

Table 9. Dry matter yield (DMY) of forage sorghum hybrids (1-28), their parents, and a hybrid check (Panar 888) averaged over years (2002-2003) and locations (Shambat, Islang)

Entry	Name	DMY (t/ha)	#
1	E-35-1 x S.70	6.680	A
3	E-35-1 x Garawi	6.540	AB
17	Dale x S.70	6.280	AB
2	E-35-1 x S.186	6.170	ABC
4	E-35-1 x Ankolib	5.880	BCD
21	N 100 x S.70	5.570	CDE
5	Hastings x s.70	5.440	DEF
16	N 109 x Ankolib	5.330	DEFG
28	Sugar Drip x Ankolib	5.260	DEFGH
40	Panar 888 (Check)	5.200	DEFGH
13	N 109 x S.70	5.120	EFGHI
12	Blue Ribbon x Ankolib	5.090	EFGHIJ
18	Dale x S. 186	4.960	EFGHIJK
36	S.70	4.910	EFGHIJKL
9	Blue Ribbon x S.70	4.780	FGHIJKLM
25	Sugar Drip x S.70	4.750	FGHIJKLM
26	Sugar Drip x S.186	4.630	GHIJKLMN
14	N 109 x S.186	4.580	GHIJKLMN
8	Hastings x Ankolib	4.570	GHIJKLMN
20	Dale x Ankolib	4.490	HIJKLMN
37	S.186	4.480	HIJKLMN
24	N 100 x Ankolib	4.390	IJKLMN
19	Dale x Garawi	4.330	JKLMN
29	E-35-1	4.280	KLMNO
7	Hastings x Garawi	4.230	KLMNO
11	Blue Ribbon x Garawi	4.200	KLMNO
10	Blue Ribbon x S.186	4.160	LMNO
23	N 100 x Garawi	4.150	LMNO
15	N 109 x Garawi	4.010	MNO
6	Hastings x S.186	3.990	MNO
22	N 100 x S.186	3.880	NO
27	Sugar Drip x Garawi	3.860	NO
38	Garawi	3.530	OP
34	N 100	3.000	PQ
39	Ankolib	2.880	PQ
33	Dale	2.780	QR
30	Hastings	2.740	QR
35	Sugar Drip	2.610	QR
31	Blue Ribbon	2.490	QR
32	N 109	2.080	R
	Mean	4.46	
	S.E.±	0.23	
	Range: Hybrids	3.86-6.68	
	Range: Parents	2.08-4.91	
	LSD(0.05)	0.648	
	LSD(0.01)	0.844	
	CV (%)	18.1	

LSD (0.05)	2.02	12.8	2.78
LSD (0.01)	2.64	16.7	3.62
C.V.%	4.0	7.2	8.8

: Means with letter in common are not significantly different at 0.05 probability level according to Duncan's multiple range test

Table 10. Performance of hybrids, their parents and a check hybrid for 3 characters in forage sorghum averaged over years (2002-2003) and locations (Shambat, Islang)

Entry		Days to flower	Plant ht (cm)	Leaf/stem ratio (percentage)
	Hybrids			
1	E-35-1 X S.70	74.3	243	35.7
2	E-35-1 X S.186	70.0	253	36.4
3	E-35-1 X Garawi	70.4	247	38.0
4	E-35-1 X Ankolib	77.6	228	41.3
5	Hastings X S.70	59.9	245	35.3
6	Hastings X S.186	55.6	241	36.1
7	Hastings X Garawi	56.3	233	38.5
8	Hastings X Ankolib	79.8	218	38.2
9	B.Ribbon X S.70	56.2	237	36.7
10	B.Ribbon X S.186	53.3	237	35.3
11	B.Ribbon X Garawi	55.3	236	39.8
12	B.Ribbon X Ankolib	63.0	239	35.9
13	N 109 X S.70	57.3	238	36.4
14	N 109 X S.186	54.1	227	36.8
15	N 109 X Garawi	54.7	232	41.1
16	N 109 X Ankolib	64.8	231	39.3
17	Dale X S.70	64.1	245	37.8
18	Dale X S.186	56.9	244	34.4
19	Dale X Garawi	58.9	234	42.0
20	Dale X Ankolib	66.2	232	41.0
21	N 100 X S.70	58.4	241	37.0
22	N 100 X S.186	54.7	216	37.3
23	N 100 X Garawi	55.7	232	39.9
24	N 100 X Ankolib	71.4	226	43.8
25	Sugar Drip X S.70	60.0	229	38.4
26	Sugar Drip X S.186	55.3	229	38.3
27	Sugar Drip X Garawi	55.8	226	40.2
28	Sugar Drip X Ankolib	66.5	242	37.5
	Parents			
29	E-35-1 ♀	82.5	171	46.1
30	Hastings "	61.1	191	43.4
31	Blue Ribbon "	55.2	197	43.5
32	N 109 "	57.3	116	53.7
33	Dale "	71.0	188	40.3
34	N 100 "	61.7	179	41.0
35	Sugar Drip "	65.9	189	44.9
36	S.70 ♂	67.2	233	34.4
37	S.186 "	54.4	227	32.6
38	Garawi "	56.2	231	40.1
39	Ankolib "	66.4	180	42.4
	Check			
40	Panar 888	67.6	217	42.8
	Mean	62.3	223	39.3
	S.E.±	0.73	4.61	1.0
	Hybrids: Range	53.3-79.8	216-253	34.4-43.8
	Parents: Range	54.4-82.5	116-233	32.6-53.7

Table 11. Performance of hybrids, their parents and a check hybrid for three characters in forage sorghum averaged over two locations (Shambat, Islang)

Entry		2002 Stem diam (cm)	2002 No. of tillers/ plant	2002 Regrowth (g/m row)	2003 Stem diam (cm)	2003 No. of tillers/ plan	2003 Regrowth (g/m row)
	Hybrids						
1	E-35-1 X S.70	2.03	2.73	253	1.77	1.34	296
2	E-35-1 X S.186	1.93	1.89	217	1.67	1.77	161
3	E-35-1 X Garawi	1.76	2.90	207	1.52	1.86	236
4	E-35-1 X Ankolib	1.83	2.62	297	1.57	1.50	210
5	Hastings X S.70	1.65	1.75	337	1.64	1.44	289
6	Hastings X S.186	1.51	1.97	291	1.56	1.50	208
7	Hastings X Garawi	1.45	2.99	506	1.56	1.90	324
8	Hastings X Ankolib	1.87	2.34	228	1.60	1.27	209
9	B.Ribbon X S.70	1.55	1.87	199	1.46	1.37	223
10	B.Ribbon X S.186	1.58	2.22	378	1.25	1.47	187
11	B.Ribbon X Garawi	1.48	2.21	295	1.33	1.93	284
12	B.Ribbon X Ankolib	1.87	2.57	330	1.51	1.75	145
13	N 109 X S.70	1.61	2.19	303	1.35	1.80	247
14	N 109 X S.186	1.40	1.95	360	1.38	1.30	250
15	N 109 X Garawi	1.44	3.25	505	1.34	1.90	310
16	N 109 X Ankolib	1.63	2.91	306	1.54	1.57	146
17	Dale X S.70	1.49	2.24	255	1.42	1.87	269
18	Dale X S.186	1.49	1.49	297	1.48	1.90	365
19	Dale X Garawi	1.53	3.11	574	1.37	2.44	325
20	Dale X Ankolib	1.65	2.71	223	1.50	2.13	322
21	N 100 X S.70	1.69	2.17	307	1.46	1.47	361
22	N 100 X S.186	1.33	2.30	388	1.39	1.77	233
23	N 100 X Garawi	1.46	2.63	339	1.24	1.54	238
24	N 100 X Ankolib	1.42	2.59	235	1.51	1.70	130
25	Sugar drip X S.70	1.64	2.28	262	1.47	1.63	242
26	Sugar drip X S.186	1.51	1.89	416	1.47	1.93	382
27	Sugar drip X Garawi	1.28	2.56	369	1.40	1.70	234
28	Sugar drip X Ankolib	1.88	2.40	252	1.83	1.24	176
	Parents						
29	E-35-1 ♀	1.54	1.50	118	1.68	1.43	126
30	Hastings ‘’	1.28	1.29	68	1.27	1.03	103
31	Blue Ribbon ‘’	1.21	1.00	45	1.18	1.00	63
32	N 109 ‘’	1.08	1.02	20	1.23	0.90	36
33	Dale ‘’	1.27	1.21	57	1.17	1.23	123
34	N 100 ‘’	1.29	1.42	94	1.35	1.56	88
35	Sugar Drip ‘’	1.18	1.60	65	1.26	0.96	99
36	S.70 ♂	1.71	1.71	137	1.82	1.57	167
37	S.186 ‘’	1.57	1.86	132	1.56	1.38	247
38	Garawi ‘’	1.31	2.89	449	1.17	2.16	408
39	Ankolib ‘’	1.46	2.31	237	1.41	1.55	291
40	Panar 888 **(Check)**	1.08	3.23	462	1.13	3.30	383
	Mean	1.52	2.19	270	1.44	1.63	228
	S.E.±	0.06	0.21	41.2	0.05	0.15	26.8
	Hybrid : Range	1.33 - 2.03	1.49 - 3.25	199 - 574	1.24 - 1.83	1.24 - 2.44	130- 382
	Parents : Range	1.08 - 1.71	1.00 - 2.89	20 - 449	1.17 - 1.82	0.90 - 2.16	36 - 408
	LSD (0.05)	0.155	0.587	115.0	0.138	0.417	74.96
	LSD (0.01)	0.205	0.775	151.8	0.182	0.550	99.0
	C.V %	8.93	23.5	37.3	8.36	22.5	28.8

Table 12. Mean squares from combined analysis of variance for green (GMY), dry (DMY) matter yield and yield related-traits of 28 forage sorghum hybrids and their parents grown over years and locations

		Mean squares					
Source of variation	**d.f.**	**GMY (t/ha)**	**DMY (t/ha)**	**Days to flower**	**Plant ht (cm)**	**Stem diam (cm)**	**Leaf/stem ratio (percentage)**
Year (Yr)	1	436.70 **	1.668 NS	2239.59 **	1868.29 **	0.799 **	204.719 **
Location (Lo)	1	1135.55 **	16.193 **	208.154 **	19192.88 **	1.801 **	1569.0 **
Yr x Lo	1	9.798 NS	0.708 NS	49.51 **	4598.93 **	0.006 NS	20.459 NS
Rep (Lo x Yr)	8	76.629 *	2.194 **	65.418 **	9975.56 **	0.027 NS	121.118 **
Treatment (E)	38	854.685 **	15.247 **	728.104 **	8885.22 **	0.412 **	183.739 **
Parent (P)	10	618.172 **	10.445 **	838.553 **	13064.32 **	0.488 **	384.088 **
Hybrid (H)	27	364.729 **	8.188 **	701.545 **	892.809 **	0.282 **	63.359 **
P vs H	1	16448.65 **	253.87 **	340.69 **	182889.5 **	3.157 **	1430.49 **
Yr x E	38	71.512 **	1.208 **	28.654 **	752.389 **	0.060 **	19.696 *
Yr x H	27	73.063 **	1.313 *	25.930 **	944.406 **	0.057 **	22.027 *
Yr x P	10	56.451 **	0.979 **	36.296 **	255.725 NS	0.027 **	15.291 *
Lo x E	38	2.059 NS	0.047 NS	0.958 NS	57.063 NS	0.002 NS	2.936 NS
Lo x H	27	1.588 NS	0.050 NS	0.477 NS	36.683 NS	0.002 NS	1.824 NS
Lo x P	10	3.034 NS	0.045 NS	2.061 NS	105.924 NS	0.002 NS	3.382 NS
Yr x Lo x E	38	3.320 NS	0.066 NS	1.154 NS	54.654 NS	0.006 NS	4.501 NS
Yr x Lo x H	27	1.997 NS	0.049 NS	0.460 NS	24.475 NS	0.003 NS	0.761 NS
Yr x Lo x P	10	6.842 NS	0.092 NS	2.212 NS	111.420 NS	0.0 12 NS	11.161 NS
Error	304	31.530	0.671	6.486	253.073	0.016	12.122

*, ** = significant at 0.05 and 0.01 probability level respectively

N.S. = non-significant at 0.05 probability level

Table 13. Mean squares from combined line x tester analysis of variance for green (GMY), dry (DMY) matter yield and yield-related traits based on data from 28 forage sorghum hybrids grown over years (Yr) and locations (Lo)

Source of variation	d.f.	Mean squares					
		GMY (t/ha)	DMY (t/ha)	Days to flower	Plant ht (cm)	Stem diam (cm)	Leaf/stem ratio (percentage)
Line (L)	6	796.872 **	20.309 **	1401.07 **	1094.33 **	0.584 **	42.740 **
Tester (T)	3	746.501 **	18.101 **	2795.20 **	1150.74 **	0.800 **	288.405 **
L x T	18	157.164 **	2.495 **	112.302 **	783.923 **	0.092 **	32.893 **
Yr x L	6	63.994 NS	0.758 NS	28.563 **	1126.39 **	0.097 **	3.818 NS
Yr x T	3	74.368 NS	2.104 *	14.283 NS	895.652 *	0.040 NS	13.478 NS
Lo x L	6	1.006 NS	0.054 NS	0.323 NS	58.491 NS	0.002 NS	2.246 NS
Lo x T	3	1.208 NS	0.011 NS	0.243 NS	42.494 NS	0.001 NS	1.211 NS
Yr x Lo x L	6	4.669 NS	0.072 NS	0.693 NS	43.438 NS	0.004 NS	1.212 NS
Yr x Lo x T	3	0.903 NS	0.024 NS	2.262 NS	12.644 NS	0.003 NS	0.825 NS
Yr x L x T	18	75.708 **	1.372 *	26.458 **	895.494 **	0.046 **	29.557 **
Lo x L x T	18	1.848 NS	0.054 NS	0.968 NS	27.930 NS	0.002 NS	1.760 NS
Yr x Lo x L x T	18	1.268 NS	0.045 NS	0.684 NS	19.778 NS	0.002 NS	0.599 NS
Error	216	35.207	0.761	7.997	291.41	0.018	14.060

*, ** = significant at 0.05 and 0.01 probability level respectively

N.S. = non-significant at 0.05 probability level

Table 14. Mean squares from single line x tester analysis of variance for tillering and regrowth of 28 forage sorghum hybrids and their parents

		No of tillers per plant				Regrowth (g/m row)			
Source of variation	d.f.	2002		2003		2002		2003	
		Shambat	Islang	Shambat	Islang	Shambat	Islang	Shambat	Islang
Rep	2	11.05**	8.411**	0.966**	0.632**	80035.2**	39492.7*	6429.6 NS	22870.8**
Hybrid (H)	27	0.626**	0.510**	0.251*	0.224*	30770.7**	23748.7**	16783.3**	12434.7**
Parent (P)	10	1.048**	0.909**	0.430**	0.414**	43869.5**	44862.7**	49125.4**	27717.5**
P vs H	1	13.34**	14.11**	2.581**	2.791**	884009.9**	820078.8**	155848.4**	240598.8**
Line (L)	6	0.256 NS	0.185 NS	0.403 NS	0.407*	23143.0 NS	15818.3 NS	17435.6 NS	13198.0 NS
Tester (T)	3	3.421**	2.916**	0.490 NS	0.474*	103997.7*	60622.7 NS	39917.6 *	30206.7*
L x T	18	0.283 NS	0.217 NS	0.161 NS	0.122 NS	21108.8 NS	20246.5**	12710.2**	9218.3**
Error	76	0.262	0.229	0.135	0.120	12389.5	8354.3	5602.2	3090.9

*, ** = significant at 0.05 and 0.01 probability level, respectively.

N.S. = non-significant at 0.05 probability level

Table 15. Estimates of general (GCA), specific (SCA) combining ability in forage sorghum and yield rank for green (GMY) and dry (DMY) matter yield from combined data, averaged over years and locations

Entry	Name		GMY			DMY		
	Hybrids		**SCA**	**(t/ha)**	**yield rank**	**SCA**	**(t/ha)**	**yield rank**
1	E-35-1	X S.70	- 0.354	50.08	1	- 0.084	6.68	1
2	E-35-1	X S.186	1.009*	48.85	2	0.042	6.17	4
3	E-35-1	X Garawi	1.242*	48.32	3	0.216*	6.54	2
4	E-35-1	X Ankolib	- 1.898**	43.27	8	- 0.174	5.88	5
5	Hastings	X S.70	1.016*	44.63	6	0.090	5.44	7
6	Hastings	X S.186	- 0.660	34.28	24	- 0.095	3.99	29
7	Hastings	X Garawi	0.896	39.22	11	0.034	4.23	24
8	Hastings	X Ankolib	- 1.252*	35.65	21	- 0.028	4.57	18
9	B.Ribbon	X S.70	- 0.871	38.79	12	- 0.129	4.78	14
10	B.Ribbon	X S.186	- 0.229	35.39	22	- 0.039	4.16	26
11	B.Ribbon	X Garawi	- 0.253	34.09	25	0.024	4.20	25
12	B.Ribbon	X Ankolib	1.352**	43.28	7	0.144	5.09	11
13	N 109	X S.70	- 0.720	37.68	16	- 0.083	5.12	10
14	N 109	X S.186	0.034	34.61	23	0.033	4.58	17
15	N 109	X Garawi	0.036	33.39	27	- 0.106	4.01	28
16	N 109	X Ankolib	0.651	39.61	10	0.156	5.33	8
17	Dale	X S.70	1.054*	45.59	4	0.219*	6.28	3
18	Dale	X S.186	0.491	38.57	14	0.075	4.96	12
19	Dale	X Garawi	- 0.761	33.59	26	- 0.085	4.33	22
20	Dale	X Ankolib	- 0.783	37.90	15	- 0.208*	4.49	19
21	N 100	X S.70	0.892	41.61	9	0.156	5.57	6
22	N 100	X S.186	- 0.866	31.01	29	- 0.113	3.88	30
23	N 100	X Garawi	0.280	33.22	28	0.027	4.15	27
24	N 100	X Ankolib	- 0.306	35.84	20	- 0.070	4.39	21
25	Sugar Drip	X S.70	- 1.016*	37.62	17	- 0.167	4.75	15
26	Sugar Drip	X S.186	0.221	36.01	19	0.096	4.63	16
27	Sugar Drip	X Garawi	- 1.441**	29.80	31	- 0.109	3.86	31
28	Sugar Drip	X Ankolib	2.236**	45.20	5	0.180	5.26	9
	S.E. $_{SCA}$		0.325	-	-	0.061	-	-
	Lines (Females)		**GCA_{Lines}**			**GCA_{Lines}**		
29	E-35-1		2.953**	30.89	30	0.474**	4.28	23
30	Hastings		- 0.234	22.41	34	- 0.116	2.74	36
31	Blue Ribbon		- 0.294	21.73	36	- 0.115	2.49	38
32	N 109		- 0.816	16.51	39	- 0.048	2.06	39
33	Dale		0.047	20.12	38	0.036	2.78	35
34	N 100		- 1.117*	22.08	35	- 0.136*	3.00	33
35	Sugar Drip		- 0.538	20.47	37	- 0.095	2.61	37
	S.E. $_{GCA\ Lines}$		0.312	-	-	0.039	-	-
	Testers (Males)		**$GCA_{Testers}$**			**$GCA_{Testers}$**		
36	S.70		1.172**	38.59	13	0.204**	4.91	13
37	S.186		- 0.603**	37.02	18	- 0.094*	4.48	20
38	Garawi		- 1.013**	28.27	32	- 0.143**	3.53	32
39	Ankolib		0.445	23.49	33	0.033	2.88	34
	S.E. $_{GCA\ Testers}$		0.104	-	-	0.017	-	-

*, ** = significantly different from zero at 0.05 and 0.01 probability level respectively.

Table 16. Estimates of general (GCA) and specific (SCA) combining ability in forage sorghum for yield-related traits, from combined data averaged over years and locations

Entry	Name	Days to flower	Plant ht (cm)	Stem diam (cm)	Leaf/stem ratio (percentage)
	SCA (Hybrid)				
1	E-35-1 X S.70	0.484	- 3.440	0.034	- 0.259
2	E-35-1 X S.186	0.497	4.059*	0.029	0.119
3	E-35-1 X Garawi	0.244	2.332	- 0.004	- 0.544
4	E-35-1 X Ankolib	- 1.225**	- 2.952	- 0.059**	0.684*
5	Hastings X S.70	- 0.922*	2.287	- 0.001	- 0.109
6	Hastings X S.186	- 0.922*	2.046	- 0.007	0.296
7	Hastings X Garawi	- 1.059**	- 0.308	0.002	- 0.110
8	Hastings X Ankolib	2.902**	- 4.025*	0.005	- 0.076
9	B.Ribbon X S.70	- 0.183	- 1.383	- 0.013	0.398
10	B.Ribbon X S.186	0.321	- 0.314	- 0.013	0.048
11	B.Ribbon X Garawi	0.587	- 0.148	0.003	0.365
12	B.Ribbon X Ankolib	- 0.725*	1.845	0.024	- 0.811*
13	N 109 X S.70	- 0.124	0.791	- 0.007	- 0.202
14	N 109 X S.186	0.239	- 1.867	- 0.008	0.056
15	N 109 X Garawi	0.332	0.070	0.011	0.314
16	N 109 X Ankolib	- 0.447	1.006	0.004	- 0.168
17	Dale X S.70	0.931*	0.945	- 0.027	0.137
18	Dale X S.186	- 0.019	1.543	0.014	- 0.872*
19	Dale X Garawi	0.268	- 1.460	0.019	0.472
20	Dale X Ankolib	- 1.181**	- 1.028	- 0.005	0.263
21	N 100 X S.70	- 0.463	2.911	0.031	- 0.362
22	N 100 X S.186	- 0.259	- 4.410*	- 0.008	- 0.125
23	N 100 X Garawi	- 0.323	1.123	0.006	- 0.455
24	N 100 X Ankolib	1.045**	0.376	- 0.029	0.942**
25	Sugar Drip X S.70	0.276	- 2.112	- 0.017	0.397
26	Sugar Drip X S.186	0.143	- 1.057	- 0.007	0.479
27	Sugar Drip X Garawi	- 0.050	- 1.610	- 0.037	- 0.042
28	Sugar Drip X Ankolib	- 0.369	4.779*	0.061**	- 0.834*
	S.E.	0.239	1.284	0.013	0.223
	GCA Lines (Females)				
29	E-35-1	3.793**	1.943	0.071**	- 0.099
30	Hastings	0.392	- 0.173	0.020	- 0.373
31	Blue Ribbon	- 1.570**	0.853	- 0.014	- 0.415
32	N 109	- 1.252**	- 0.858	- 0.029	0.079
33	Dale	- 0.054	1.259	- 0.017	0.212
34	N 100	- 0.547*	- 1.941	- 0.036*	0.446
35	Sugar Drip	- 0.763**	- 1.084	0.005	0.150
	S.E.	0.120	0.951	0.009	0.159
	GCA Testers (Males)				
36	S.70	- 0.075	1.275	0.014	- 0.470**
37	S.186	- 1.521**	0.173	- 0.016	- 0.593**
38	Garawi	- 1.138**	- 0.161	- 0.035*	0.586*
39	Ankolib	2.734**	- 1.286	0.038*	0.478*
	S.E.	0.164	0.388	0.006	0.099

Table 17. Estimates of general (GCA) and specific (SCA) combining ability in forage sorghum, for number of tillers per plant, from single analysis of variance

*, ** = significantly different from zero at 0.05 and 0.01 probability level respectively.

Table 17. Estimates of general (GCA) and specific (SCA) combining ability in forage sorghum, for number of tillers per plant, from single analysis of variance

Entry	Name	Shambat 2002	Shambat 2003	Islang 2002	Islang 2003
	SCA (Hybrid)	**Number of tillers per plant**			
1	E-35-1 X S.70	0.388	- 0.158	0.287	- 0.160
2	E-35-1 X S.186	- 0.221	0.147	- 0.169	0.184
3	E-35-1 X Garawi	- 0.031	0.036	- 0.049	0.017
4	E-35-1 X Ankolib	- 0.136	- 0.025	- 0.069	- 0.041
5	Hastings X S.70	- 0.329	0.034	- 0.261	0.015
6	Hastings X S.186	0.195	- 0.028	0.057	0.002
7	Hastings X Garawi	0.286	0.161	0.310	0.141
8	Hastings X Ankolib	- 0.152	- 0.166	- 0.106	- 0.157
9	B.Ribbon X S.70	- 0.104	- 0.133	- 0.153	- 0.151
10	B.Ribbon X S.186	0.454	- 0.162	0.395	- 0.131
11	B.Ribbon X Garawi	- 0.489	0.094	- 0.378	0.078
12	B.Ribbon X Ankolib	0.139	0.200	0.135	0.204
13	N 109 X S.70	- 0.187	0.284	- 0.146	0.270
14	N 109 X S.186	- 0.230	- 0.345	- 0.175	- 0.302
15	N 109 X Garawi	0.227	0.044	0.265	0.037
16	N 109 X Ankolib	0.189	0.017	0.055	- 0.005
17	Dale X S.70	0.071	- 0.094	0.071	- 0.103
18	Dale X S.186	- 0.505	- 0.189	- 0.455	- 0.149
19	Dale X Garawi	0.319	0.143	0.272	0.133
20	Dale X Ankolib	0.114	0.140	0.112	0.119
21	N 100 X S.70	- 0.079	- 0.025	0.015	- 0.035
22	N 100 X S.186	0.279	0.147	0.313	0.183
23	N 100 X Garawi	- 0.164	- 0.298	- 0.270	- 0.302
24	N 100 X Ankolib	- 0.036	0.175	- 0.057	0.154
25	Sugar Drip X S.70	0.238	0.092	0.187	0.163
26	Sugar Drip X S.186	0.029	0.430	0.035	0.213
27	Sugar Drip X Garawi	- 0.148	- 0.181	- 0.151	- 0.104
28	Sugar Drip X Ankolib	- 0.119	- 0.341	- 0.071	- 0.272
	S.E.	0.296	0.212	0.276	0.200
	GCA Lines (Females)				
29	E-35-1	0.112	- 0.066	0.144	- 0.057
30	Hastings	- 0.105	- 0.158	- 0.131	- 0.138
31	Blue Ribbon	- 0.196	- 0.058	- 0.123	- 0.039
32	N 109	0.220	- 0.041	0.174	- 0.031
33	Dale	- 0.005	0.403**	0.020	0.410**
34	N 100	0.079	- 0.066	0.009	- 0.056
35	Sugar Drip	- 0.105	- 0.016	- 0.093	- 0.090
	S.E.	0.148	0.106	0.138	0.100
	GCA Testers (Males)				
36	S.70	- 0.238	- 0.125	- 0.198	- 0.114
37	S.186	- 0.429**	0.003	- 0.413**	- 0.034
38	Garawi	0.448**	0.214	0.407**	0.220*

Table 18. Estimates of general (GCA) and specific (SCA) combining ability in forage sorghum, for regrowth, from single analysis of variance

39 Ankolib 0.219 - 0.092 0.204 - 0.072

S.E. 0.112 0.080 0.104 0.076

*, ** = significantly different from zero at 0.05 and 0.01 probability level respectively

Entry	Name	Shambat 2002	Shambat 2003	Islang 2002	Islang 2003
	SCA (Hybrids)	**Regrowth (g/m row)**			
1	E-35-1 X S.70	52.6	44.2	56.6	45.2
2	E-35-1 X S.186	- 46.9	- 70.2	- 39.4	- 69.0
3	E-35-1 X Garawi	-119.6	- 23.0	- 114.3	- 13.5
4	E-35-1 X Ankolib	113.9	49.0	97.1	37.3
5	Hastings X S.70	48.0	3.55	35.3	9.87
6	Hastings X S.186	- 51.5	- 53.9	- 80.4	- 54.3
7	Hastings X Garawi	92.5	36.0	77.1	38.5
8	Hastings X Ankolib	- 89.0	14.4	- 31.9	5.92
9	B.Ribbon X S.70	- 45.3	- 14.0	- 67.2	- 10.0
10	B.Ribbon X S.186	73.2	- 24.7	49.2	- 31.6
11	B.Ribbon X Garawi	- 87.1	53.1	- 84.7	38.3
12	B.Ribbon X Ankolib	59.3	- 14.5	102.7	3.33
13	N 109 X S.70	- 23.9	- 8.04	- 17.2	- 25.5
14	N 109 X S.186	- 32.4	- 16.5	- 16.9	29.7
15	N 109 X Garawi	51.3	58.7	61.6	27.9
16	N 109 X Ankolib	5.04	- 34.2	- 27.4	- 32.1
17	Dale X S.70	- 36.0	- 83.8	- 38.5	- 68.6
18	Dale X S.186	- 59.5	41.1	- 52.8	37.5
19	Dale X Garawi	164.2	- 23.4	148.7*	- 24.3
20	Dale X Ankolib	- 68.7	66.0	- 57.3	55.4
21	N 100 X S.70	24.2	100.0	45.8	90.6*
22	N 100 X S.186	45.4	- 5.13	63.1	- 20.2
23	N 100 X Garawi	- 60.0	- 26.6	- 57.1	- 35.4
24	N 100 X Ankolib	- 9.55	- 68.2	- 51.8	- 35.0
25	Sugar Drip X S.70	- 19.5	- 42.0	- 14.7	- 41.5
26	Sugar Drip X S.186	71.7	129.3*	77.3	107.9*
27	Sugar Drip X Garawi	- 41.3	- 74.9	- 31.3	- 31.5
28	Sugar Drip X Ankolib	- 10.9	- 12.5	- 31.3	- 34.8
	S.E.	64.3	43.2	52.8	32.1
	GCA Lines (Females)				
29	E-35-1	- 81.3	- 22.0	- 69.6	- 26.9
30	Hastings	17.6	11.4	25.5	3.42
31	Blue Ribbon	- 30.4	- 40.8	- 6.46	- 39.7
32	N 109	56.8	- 20.1	42.6	- 3.92
33	Dale	16.6	76.7*	19.9	63.9**
34	N 100	10.4	- 11.1	- 13.0	- 8.00
35	Sugar Drip	10.4	5.86	1.12	11.2
	S.E.	32.1	21.6	26.4	16.0
	GCA Testers (Males)				
36	S.70	- 45.3	30.5	- 45.1	19.9
37	S.186	23.2	5.63	9.57	4.07
38	Garawi	88.6**	27.1	72.1*	30.5
39	Ankolib	- 66.5	- 63.3**	- 36.6	- 54.5**

S.E.	24.3	16.3	19.9	12.1

*, ** = significantly different from zero at 0.05 and 0.01 probability level respectively

Table 19. Variance components of general (σ² GCA) and specific (σ² SCA) combining ability, their interactions over years (Yr), locations (LO) and GCA/SCA variance ratio for green (GMY), dry (DMY) matter yield and yield-related traits, based on data from 28 forage sorghum hybrids

Variance components #		GMY (t/ha)	DMY (t/ha)	Days to flower	Plant ht (cm)	Stem diam (cm)	Leaf/stem ratio (percentage)
σ^2 $GCA_{Lines\ (L)}$	(1)	13.33**	0.371**	26.85**	6.467**	0.010**	0.205**
σ^2 $GCA_{Tester\ (T)}$	(2)	7.016**	0.186**	31.94**	4.367**	0.008**	3.042**
σ^2 SCA_{LxT}	(3)	10.16**	0.145**	8.692**	41.04**	0.006**	1.569**
σ^2 $GCA_{L\ x\ YR}$		- 0.488	- 0.026	0.088**	9.621**	0.002**	- 1.072
σ^2 $GCA_{T\ x\ YR}$		- 0.032	0.017*	- 0.290	0.004*	0.0001	- 0.383
σ^2 $GCA_{L\ x\ LO}$		- 0.035	0.000	- 0.027	1.273	0.000	0.028
σ^2 $GCA_{T\ x\ LO}$		- 0.015	- 0.001	- 0.017	0.347	0.000	- 0.013
σ^2 $GCA_{L\ x\ YR\ x\ LO}$		0.283	- 0.002	0.001	1.972	0.0002	0.051
σ^2 $GCA_{T\ x\ YR\ x\ LO}$		- 0.017	- 0.001	0.075	- 0.340	0.000	0.011
σ^2 $SCA_{LxT\ x\ YR}$		12.41**	0.221*	4.296**	145.95**	0.007**	4.826**
σ^2 $SCA_{LxT\ x\ LO}$		0.097	- 0.002	0.047	1.359	0.000	0.194
σ^2 $SCA_{LxT\ YR\ x\ LO}$		- 11.31	- 0.239	- 2.438	- 90.54	- 0.005	- 4.487
Error mean square		35.207	0.761	7.997	291.41	0.018	14.06
σ^2 GCA / σ^2 SCA ratio = (1+2)/3		2.003	3.841	6.764	0.264	3.0	2.069

*, ** = significant at 0.05 and 0.01 probability level respectively
= negative component interpreted as zero

Experiment		σ^2 GCA $_{Line(L)}$	σ^2 GCA $_{Tester(T)}$	σ^2 SCA $_{LxT}$	σ^2 GCA / σ^2 SCA
Location	year				
		Number of tillers per plant			
Shambat	2002	- 0.002 #	0.149**	0.007	21.3
Shambat	2003	0.020	0.016	0.009	4.0
Islang	2002	- 0.003	0.129**	- 0.004	-
Islang	2003	0.024*	0.017*	0.001	41.0
		Regrowth (g/m row)			
Shambat	2002	169.5	3947.1*	2906.4	1.4
Shambat	2003	393.8	1295.6*	2369.3**	0.71
Islang	2002	- 369.0	1922.7	3964.1**	0.49
Islang	2003	331.6	999.4*	2042.5**	0.65

Table 20. Variance components of general (σ^2 GCA), specific (σ^2 SCA) combining ability and GCA/SCA variance ratio from single line x tester analysis, for green (GMY), dry (DMY) matter yield and yield-related traits based on data from 28 forage sorghum hybrids

*, ** = significant at 0.05 and 0.01 probability level respectively

: = negative components interpreted as zero

Table 21. Contribution of lines, testers, and lines x testers to the total variance, for six characters in forage sorghum, from combined analysis of variance

Character	Lines	Testers	Lines x Testers
	Contribution (percentage)		
Green matter yield (t/ha)	48.6	22.7	28.7
Dry matter yield (t/ha)	55.1	24.6	20.3
Days to flower	44.4	44.3	10.7
Plant height (cm)	26.1	14.3	58.5
Stem diameter (cm)	46.0	31.5	21.8
Leaf/stem ratio (percentage)	15.0	50.6	34.6

Table 22. Contribution of lines, testers, and lines x testers to the total variance, for 2 characters in forage sorghum, from single analysis of variance

Experiment		Character	Lines	Testers	Lines x Testers
Location	**year**		**Contribution (Percentage)**		
Shambat	2002	Number of tillers per plant	9.1	60.7	30.2
		Regrowth (g/m row)	16.7	37.6	45.7
Shambat	2003	Number of tillers per plant	35.6	21.7	42.7
		Regrowth (g/m row)	23.1	26.4	50.5
Islang	2002	Number of tillers per plant	8.1	63.6	28.3
		Regrowth (g/m row)	14.8	28.4	56.8
Islang	2003	Number of tillers per plant	40.3	23.5	36.2
		Regrowth (g/m row)	23.6	27.0	49.4

Table 23. Heterosis over mid (MP), better (BP) parent and percentage deviation over the commercial hybrid (CH), for green (GMY) and dry (DMY) matter yield, from combined data of forage sorghum hybrids and their parents, grown for 2 years at 2 locations

		Percentage					
		GMY (t/ha)			DMY (t/ha)		
Entry	Hybrid	MP	BP	CH	MP	BP	CH
1	E-35-1 X S.70	44.2**	29.8**	24.3**	45.4**	36.1**	28.5**
2	E-35-1 X S.186	43.7**	31.9**	21.1**	40.9**	37.7**	18.7**
3	E-35-1 X Garawi	63.2**	56.3**	19.9**	67.5**	52.8**	25.8**
4	E-35-1 X Ankolib	59.2**	40.1**	7.44	64.3**	37.4**	13.1
5	Hastings X S.70	46.2**	15.5**	10.7*	42.2**	10.8	4.62
6	Hastings X S.186	15.5*	- 7.30	- 14.9**	10.5	- 10.9	- 23.3**
7	Hastings X Garawi	54.6**	38.5**	- 2.73	34.9**	19.8*	- 18.7**
8	Hastings X Ankolib	55.1**	51.5**	- 11.7*	62.6**	58.7**	- 12.1
9	B.Ribbon X S.70	28.7**	0.52	- 3.72	29.2**	- 2.65	- 8.08
10	B.Ribbon X S.186	20.6**	- 4.32	- 12.2*	19.4**	- 7.14	- 20.0**
11	B.Ribbon X Garawi	36.4**	20.5*	- 15.4**	39.5**	19.0*	- 19.2**
12	B.Ribbon X Ankolib	91.6**	84.3**	7.44	89.6**	76.7**	-2.12
13	N 109 X S.70	36.8**	- 2.33	- 6.45	46.5**	4.28	- 1.54
14	N 109 X S.186	29.4**	- 6.49	- 14.1*	36.6**	2.23	- 11.9
15	N 109 X Garawi	49.1**	18.0*	- 17.1**	43.0**	13.6	- 22.9**
16	N 109 X Ankolib	98.0**	68.5**	- 1.74	114.9**	85.1**	2.50
17	Dale X S.70	55.4**	18.1**	13.2*	63.3**	27.9**	20.8**
18	Dale X S.186	35.2**	4.32	- 4.22	36.6**	10.7	- 4.62
19	Dale X Garawi	38.8**	18.7*	- 16.6**	37.2**	22.7*	- 16.7**
20	Dale X Ankolib	73.9**	61.3**	- 5.96	58.7**	55.9**	- 13.7*
21	N 100 X S.70	37.1**	7.77	3.23	40.8**	13.4	7.12
22	N 100 X S.186	4.91	- 16.2**	- 23.1**	3.74	- 13.4	- 25.4**
23	N 100 X Garawi	31.8**	17.3*	- 17.6**	27.1**	17.6	- 20.2**
24	N 100 X Ankolib	57.0**	52.3**	- 11.2*	49.3**	46.3**	- 15.6*
25	Sugar Drip X S.70	27.2**	- 2.59	- 6.70	26.3**	- 3.26	- 8.65
26	Sugar Drip X S.186	25.2**	- 2.70	- 10.7	30.6**	3.35	- 11.0
27	Sugar Drip X Garawi	22.1*	5.30	-26.1**	25.7**	9.35	- 25.8**
28	Sugar Drip X Ankolib	105.5**	92.3**	12.2*	91.6**	82.6**	1.15

Table 24. Heterosis over mid (MP), better (BP) parents and percentage deviation over the commercial hybrid (CH) for 2 characters of forage sorghum hybrids and their parents grown for 2 years at 2 locations

Mean	45.9	24.7	-3.67	45.6	25.2	-5.69
Range	4.91	- 16.2	- 23.1	3.74	- 13.4	- 25.8
	105.5	[illegible]	24.3	114.9	[illegible]	28.5

*, ** = significant at 0.05 and 0.01 probability level respectively.

		Percentage					
		Days to flower			Plant ht (cm)		
Entry	Hybrid	MP	BP #	CH	MP	BP	CH
1	E-35-1 X S.70	- 0.73	10.6**	9.91**	20.3**	4.29	12.0**
2	E-35-1 X S.186	2.26	28.7**	3.55*	27.1**	11.5**	16.6**
3	E-35-1 X Garawi	1.51	25.3**	4.14**	22.9**	6.93*	13.8**
4	E-35-1 X Ankolib	4.23**	16.9**	14.8**	29.9**	26.7**	5.07
5	Hastings X S.70	- 6.63**	- 1.96	- 11.4**	15.6**	5.15	12.9**
6	Hastings X S.186	- 3.72*	2.21	- 17.8**	15.3**	6.17*	11.1**
7	Hastings X Garawi	- 4.01*	0.18	- 16.7**	10.4**	0.87	7.37*
8	Hastings X Ankolib	25.2**	30.6**	18.1**	17.5**	14.1**	0.46
9	B.Ribbon X S.70	- 8.17**	1.81	- 16.9**	10.2**	1.72	9.22**
10	B.Ribbon X S.186	- 2.74	- 3.44	- 21.2**	11.8**	4.41	9.22**
11	B.Ribbon X Garawi	- 0.72	0.18	- 18.2**	10.3**	2.16	8.76**
12	B.Ribbon X Ankolib	3.62*	14.1**	- 6.80**	26.8**	21.3**	10.1**
13	N 109 X S.70	- 7.95**	0.00	- 15.2**	36.4**	2.15	9.68**
14	N 109 X S.186	- 3.13	- 0.55	- 20.0**	32.4**	0.00	4.61
15	N 109 X Garawi	- 3.61*	- 2.67	- 19.1**	33.7**	0.43	6.91*
16	N 109 X Ankolib	4.77**	13.1**	- 4.14*	56.1**	28.3**	6.45*
17	Dale X S.70	- 7.24**	- 4.61**	- 5.18**	16.4**	5.15	12.9**
18	Dale X S.186	- 9.25**	4.60**	- 15.8**	17.6**	7.49**	12.4**
19	Dale X Garawi	- 7.39**	4.80**	- 12.9**	11.7**	1.30	7.83*
20	Dale X Ankolib	- 3.64*	- 0.30	- 2.07	26.1**	23.4**	6.91*
21	N 100 X S.70	- 9.39**	- 5.35**	- 13.6**	17.0**	3.43	11.1**
22	N 100 X S.186	- 5.77**	0.55	- 19.1**	6.40*	- 4.85	- 0.46
23	N 100 X Garawi	- 5.51**	- 0.89	- 17.6**	13.2**	0.43	6.91*
24	N 100 X Ankolib	11.5**	15.7**	5.62**	25.9**	25.6**	4.15
25	Sugar Drip X S.70	- 9.84**	- 8.95**	- 11.2**	8.53**	- 1.72	5.53
26	Sugar Drip X S.186	- 8.06**	1.65	- 18.2**	10.1**	0.88	5.53
27	Sugar Drip X Garawi	- 8.60**	- 0.71	- 17.5**	7.62*	- 2.16	4.15
28	Sugar Drip X Ankolib	0.53	0.91	- 1.63	31.2**	28.0**	11.5**
	Mean	-2.23	5.09	-8.79	20.3	7.97	8.31
	Range	- 9.84	- 8.95	- 21.2	6.40	- 4.85	- 0.46

Table 25. Heterosis over mid (MP), better (BP) parents and percentage deviation over the commercial hybrid (CH) for 2 characters of forage sorghum hybrids grown for 2 years at 2 locations

11.5 30.6 18.1 56.1 28.3 16.6

*, ** = significant at 0.05 and 0.01 probability level respectively.
: Better parent = lower values (negative values desirable)

		Percentage					
		Stem diam (cm)			Leaf/stem ratio (percentage)		
Entry	hybrid	MP	BP #	CH	MP	BP	CH
1	E-35-1 X S.70	12.8**	18.0**	72.7**	- 11.3**	- 22.6**	- 16.6**
2	E-35-1 X S.186	13.6**	15.4**	63.6**	- 7.5*	- 21.0**	- 15.0**
3	E-35-1 X Garawi	15.1**	32.3**	49.1**	- 11.8**	- 17.6**	- 11.2**
4	E-35-1 X Ankolib	11.5**	18.1**	54.6**	- 6.67*	- 10.4**	- 3.50
5	Hastings X S.70	8.25*	29.1**	49.1**	- 9.25*	- 18.7**	- 17.5**
6	Hastings X S.186	8.83*	21.3**	40.0**	- 5.00	- 16.8**	- 15.7**
7	Hastings X Garawi	20.3**	21.8**	37.3**	- 7.78*	- 11.3**	- 10.1**
8	Hastings X Ankolib	27.7**	36.2**	57.3**	- 11.0**	- 12.0**	- 10.8**
9	B.Ribbon X S.70	1.35	25.0**	36.4**	- 5.78	- 15.6**	- 14.3**
10	B.Ribbon X S.186	2.17	17.5**	28.2**	- 7.23	- 18.9**	- 17.5**
11	B.Ribbon X Garawi	14.8**	16.7**	27.3**	- 4.78	- 8.51**	- 7.01*
12	B.Ribbon X Ankolib	28.0**	40.8**	53.6**	- 16.4**	- 17.5**	- 16.1**
13	N 109 X S.70	1.72	28.7**	34.6**	- 17.4**	- 32.2**	- 15.0**
14	N 109 X S.186	2.58	20.9**	26.4**	- 14.7**	- 31.5**	- 14.0**
15	N 109 X Garawi	16.3**	20.9**	26.4**	- 12.4**	- 23.5**	- 3.97
16	N 109 X Ankolib	22.0**	37.4**	43.6**	- 18.2**	- 26.8**	- 8.18*
17	Dale X S.70	- 2.68	18.9**	31.8**	1.20	- 6.20	- 11.7**
18	Dale X S.186	7.19	22.1**	35.5**	- 5.62	- 14.6**	- 19.6**
19	Dale X Garawi	17.9**	18.9**	31.8**	4.48	4.22	- 1.87
20	Dale X Ankolib	18.8**	29.5**	43.6**	- 0.85	- 3.30	- 4.21
21	N 100 X S.70	1.95	18.9**	42.7**	- 1.86	- 9.76**	- 13.6**
22	N 100 X S.186	- 5.56	3.03	23.6**	1.36	- 9.02**	- 12.9**
23	N 100 X Garawi	5.47	8.87*	22.7**	- 1.60	- 2.68	- 6.78*
24	N 100 X Ankolib	5.80	10.6**	32.7**	5.04	3.30	2.34
25	Sugar Drip X S.70	4.03	27.1**	40.9**	- 3.15	- 14.5**	- 10.3**
26	Sugar Drip X S.186	7.19	22.1**	35.5**	- 1.16	- 14.7**	- 10.5**
27	Sugar Drip X Garawi	8.94*	9.84*	21.8**	- 5.41	- 10.5**	- 6.07
28	Sugar Drip X Ankolib	39.9**	52.5**	69.1**	- 14.1**	- 16.5**	- 12.4**
	Mean	11.28	22.94	40.43	- 6.75	-14.26	-10.86
	Range	- 5.56	3.03	21.8	- 18.2	- 32.2	- 19.6

Table 26. Heterosis over mid (MP), better (BP) parent and percentage deviation over commercial hybrid (CH) for number of tillers per plant of forage sorghum hybrids and their parents, grown at Shambat (2002- 2003)

39.9 51.5 72.7 5.04 4.22 2.34

*, ** = significant at 0.05 and 0.01 probability level respectively.
: Better parent = lower values (negative values desirable)

		Number of tillers per plant					
		Shambat (2002)			Shambat (2003)		
Entry	Hybrid	MP	BP	CH	MP	BP	CH
		Percentage					
1	E-35-1 X S.70	63.5*	54.2*	- 21.3	- 11.3	- 15.3	- 61.7**
2	E-35-1 X S.186	10.3	0.00	- 44.4**	26.0	23.8	- 49.0**
3	E-35-1 X Garawi	31.3	0.00	- 13.5	3.89	- 13.8	- 46.1**
4	E-35-1 X Ankolib	31.2	6.80	- 23.1	- 1.96	- 7.98	- 56.8**
5	Hastings X S.70	14.7	1.69	- 48.1**	10.0	- 8.92	- 58.8**
6	Hastings X S.186	29.1	10.4	- 38.6*	24.5	8.70	- 56.8**
7	Hastings X Garawi	41.9*	3.33	- 10.7	18.8	- 12.4	- 45.2**
8	Hastings X Ankolib	25.6	- 2.80	- 30.0*	- 4.51	- 22.1	- 63.4**
9	B.Ribbon X S.70	35.9	9.04	- 44.4**	6.61	- 12.7	- 60.5**
10	B.Ribbon X S.186	53.3	19.2	- 33.7*	23.5	6.52	- 57.6**
11	B.Ribbon X Garawi	9.58	- 25.7	- 35.7**	21.8	- 11.1	- 44.4**
12	B.Ribbon X Ankolib	47.3	5.20	- 24.2	31.6	6.13	- 50.1**
13	N 109 X S.70	58.2	28.3	- 34.6**	45.8	14.7	- 48.1**
14	N 109 X S.186	34.0	5.18	- 41.5**	14.0	- 5.80	- 62.5**
15	N 109 X Garawi	64.4**	12.3	- 2.88	23.8	- 12.4	- 45.2**
16	N 109 X Ankolib	72.2**	24.0	- 10.7	24.1	- 3.68	- 54.8**
17	Dale X S.70	49.8	29.9	- 33.7*	33.6	19.1	- 46.1**
18	Dale X S.186	- 5.26	- 20.7	- 55.9**	45.6	37.7	- 45.2**
19	Dale X Garawi	50.2*	7.67	- 6.92	43.5*	12.4	- 29.7**
20	Dale X Ankolib	47.4*	12.0	- 19.3	49.0*	30.7	- 38.6**
21	N 100 X S.70	36.4	26.0	- 35.7**	- 6.37	- 6.37	- 57.6**
22	N 100 X S.186	39.9	24.4	- 30.8*	20.0	12.7	- 49.0**
23	N 100 X Garawi	25.8	- 5.67	- 18.4	- 18.2	- 29.5*	- 55.9**
24	N 100 X Ankolib	36.5	9.20	- 21.3	6.25	4.29	- 51.0**
25	Sugar Drip X S.70	31.7	29.5	- 31.7*	28.4	3.82	- 53.0**
26	Sugar Drip X S.186	4.79	2.07	- 43.2**	78.7**	52.2*	- 39.5**
27	Sugar Drip X Garawi	10.6	- 11.0	- 23.1	8.28	- 21.7	- 51.0**
28	Sugar Drip X Ankolib	14.1	- 1.20	- 28.8*	- 5.38	- 24.5	- 64.6**

Table 27. Heterosis over mid (MP), better (BP) parent and percentage deviation over commercial hybrid (CH) for number of tillers per plant of forage sorghum hybrids and their parents, grown at Islang (2002- 2003)

	MP	BP	CH	MP	BP	CH
Mean	34.4	9.03	- 26.8	19.3	0.86	- 51.5
Range	- 5.26	- 25.7	- 55.9	- 18.2	- 29.5	- 64.6
	72.2	54.2	- 2.88	78.7	52.2	– 29.7

*, ** = significant at 0.05 and 0.01 probability level respectively.

Table 27. Heterosis over mid (MP), better (BP) parent and percentage deviation over commercial hybrid (CH) for number of tillers per plant of forage sorghum hybrids and their parents, grown at Islang (2002- 2003)

		Number of tillers per plant					
		Islang (2002)			Islang (2003)		
Entry	Hybrid	MP	BP	CH	MP	BP	CH
		percentage					
1	E-35-1 X S.70	77.3**	64.5**	- 9.00	- 10.4	- 14.7	- 57.2**
2	E-35-1 X S.186	15.3	3.35	- 38.3**	26.4	24.7	- 43.5**
3	E-35-1 X Garawi	33.2	0.72	- 7.00	3.35	- 14.4	- 40.9**
4	E-35-1 X Ankolib	45.2*	21.2	- 14.3	3.81	2.04	- 52.1**
5	Hastings X S.70	18.1	2.41	- 43.3**	11.2	- 8.28	- 54.0**
6	Hastings X S.186	19.6	0.56	- 40.0**	25.0	8.70	- 52.1**
7	Hastings X Garawi	43.9*	3.61	- 4.33	19.5	- 12.0	- 39.3**
8	Hastings X Ankolib	34.7	6.13	- 25.0	2.01	- 13.6	- 59.4**
9	B.Ribbon X S.70	39.8	9.04	- 39.7**	7.03	- 12.7	- 56.2**
10	B.Ribbon X S.186	58.1*	20.1	- 28.3*	24.1	6.52	- 53.0**
11	B.Ribbon X Garawi	18.4	- 20.9	- 27.0*	22.5	- 10.7	- 38.4**
12	B.Ribbon X Ankolib	63.9*	17.9	- 16.7	43.9	20.4	- 43.5**
13	N 109 X S.70	63.7*	27.7	- 29.3*	46.3	14.7	- 42.5**
14	N 109 X S.186	37.5	4.47	- 37.7**	15.4	- 5.07	- 58.2**
15	N 109 X Garawi	69.2**	13.0	4.33	24.6	- 12.0	- 39.3**
16	N 109 X Ankolib	78.4**	28.3	- 9.33	33.1	6.80	- 49.8**
17	Dale X S.70	56.3*	31.3	- 27.3*	34.1	19.1	- 40.3**
18	Dale X S.186	- 1.37	- 19.6	- 52.0**	46.2*	37.7	- 39.3**
19	Dale X Garawi	53.3**	7.94	- 0.33	44.4*	13.0	- 22.0*
20	Dale X Ankolib	61.2*	23.6	- 12.7	58.4**	44.9*	- 32.0**
21	N 100 X S.70	41.1	27.1	- 29.7*	- 5.77	- 6.37	- 53.0**
22	N 100 X S.186	41.0	22.9	- 26.7*	20.8	14.2	- 43.5**
23	N 100 X Garawi	18.5	- 12.3	- 19.0	- 17.0	- 28.7*	- 50.8**
24	N 100 X Ankolib	41.5	15.1	- 18.7	12.6	9.68	- 45.7**
25	Sugar Drip X S.70	43.9	31.3	- 27.3*	28.9	3.82	- 47.9**
26	Sugar Drip X S.186	15.2	1.68	- 39.3**	50.4*	27.5	- 43.8**
27	Sugar Drip X Garawi	18.4	- 11.7	- 18.3	8.97	- 21.3	- 45.7**

28 Sugar Drip X Ankolib	33.5	9.01	-22.5	2.06	-15.7	-60.4**
Mean	40.7	11.8	-23.5	20.8	2.8	-46.6
Range	- 1.37 78.4	- 20.9 64.5	- 52.0 4.33	- 17.0 58.4	- 28.7 77.0	- 60.4 22.0

*, ** = significant at 0.05 and 0.01 probability level respectively.

Table 28. Heterosis over mid (MP), better (BP) parent and percentage deviation over commercial hybrid (CH) for regrowth of forage sorghum hybrids and their parents, grown at Shambat (2002- 2003)

Entry	Hybrid		Regrowth (g/m row) Shambat (2002) MP	BP	CH	Shambat (2003) MP	BP	CH
			Percentage					
1	E-35-1	X S.70	90.2	77.5	- 44.3*	102.0*	76.7*	- 30.4*
2	E-35-1	X S.186	70.7	62.5	- 51.1*	- 16.5	- 38.0	- 62.2**
3	E-35-1	X Garawi	- 24.3	- 51.6*	- 52.7**	- 21.0	- 49.5**	- 46.5**
4	E-35-1	X Ankolib	53.7	13.6	- 35.4	- 3.59	- 32.2	- 50.8**
5	Hastings	X S.70	224.3**	144.4*	- 23.2	112.9*	72.7*	- 32.0*
6	Hastings	X S.186	203.9*	132.4*	- 30.1	15.3	- 19.2	- 50.8**
7	Hastings	X Garawi	104.3**	18.8	16.2	14.4	- 29.6*	- 25.4
8	Hastings	X Ankolib	14.3	- 26.9	- 58.4**	0.94	- 32.5	- 51.0**
9	B.Ribbon	X S.70	120.4	44.4	- 54.7**	90.8	32.0	- 48.1**
10	B.Ribbon	X S.186	335.6**	188.2**	- 13.3	15.7	- 27.8	- 56.1**
11	B.Ribbon	X Garawi	22.2	- 32.8	- 34.3	10.0	- 37.2**	- 33.4*
12	B.Ribbon	X Ankolib	92.0	12.5	- 36.1	- 30.6	- 58.0**	- 69.6**
13	N 109	X S.70	287.7*	121.1	- 30.5	143.1*	47.7	- 41.9**
14	N 109	X S.186	379.5**	175.0**	- 17.3	45.9	- 16.9	- 49.4**
15	N 109	X Garawi	126.4**	18.3	15.7	26.8	- 31.5*	- 27.5
16	N 109	X Ankolib	132.5*	25.3	- 28.8	- 24.3	- 57.7**	- 69.3**
17	Dale	X S.70	158.1	84.5	- 42.0*	84.0*	59.9	- 37.1**
18	Dale	X S.186	211.7*	125.7	- 32.1	90.8**	41.0	- 14.2
19	Dale	X Garawi	137.0**	34.8	31.9	12.5	- 28.3*	- 24.0
20	Dale	X Ankolib	30.8	- 19.1	- 54.0**	49.1	4.42	- 24.3
21	N 100	X S.70	161.2*	122.5	- 30.1	182.1**	115.7**	- 15.1
22	N 100	X S.186	243.2**	197.8**	- 10.4	35.0	- 9.40	- 44.9**
23	N 100	X Garawi	34.7	- 17.4	- 19.3	- 13.0	- 48.0**	- 44.9**
24	N 100	X Ankolib	46.2	1.56	- 42.3*	- 46.6	- 65.6**	- 75.1**
25	Sugar Drip	X S.70	160.3	91.6	- 39.8*	80.2	43.0	- 43.7**
26	Sugar Drip	X S.186	325.6**	217.7**	- 4.42	113.6**	47.4*	- 10.3
27	Sugar Drip	X Garawi	50.9	- 13.1	- 15.0	- 25.5	- 54.6**	- 52.0**
28	Sugar Drip	X Ankolib	59.9	0.78	- 42.7*	- 12.9	- 42.6*	- 58.4**
	Mean		137.6	62.5	-27.8	36.8	-4.93	-42.4
	Range		- 24.3	- 51.6	- 58.4	- 46.6	- 65.6	- 75.1

379.5 217.7 31.9 182.1 115.7 – 10.3

Table 29. Heterosis over mid (MP), better (BP) parent and percentage deviation over commercial hybrid (CH) for regrowth of forage sorghum hybrids and their parents, grown at Islang (2002- 2003)

*, ** = significant at 0.05 and 0.01 probability level respectively.

		Regrowth (g/m row)					
		Islang (2002)			Islang (2003)		
Entry	Hybrid	MP	BP	CH	MP	BP	CH
		Percentage					
1	E-35-1 X S.70	106.5	91.7	- 46.4**	102.1**	77.2**	- 12.8
2	E-35-1 X S.186	76.7	66.9	- 55.1**	- 10.0	- 30.8	- 52.3**
3	E-35-1 X Garawi	- 29.7	- 56.1**	- 57.6**	0.84	- 32.1*	- 27.4*
4	E-35-1 X Ankolib	83.0	39.2	- 36.0*	5.70	- 22.7	- 38.0**
5	Hastings X S.70	233.7**	147.7**	- 30.7	115.3**	74.1**	- 14.3
6	Hastings X S.186	178.5*	109.5	- 43.6**	23.6	- 11..0	- 38.6**
7	Hastings X Garawi	86.9**	6.58	2.97	42.0*	- 8.81	- 2.43
8	Hastings X Ankolib	90.8	23.5	- 43.2**	11.5	- 23.1	- 38.3**
9	B.Ribbon X S.70	116.9	46.2	- 59.1**	97.3*	35.2	- 33.4**
10	B.Ribbon X S.186	320.8**	186.6**	- 22.9	26.1	- 20.3	- 45.0**
11	B.Ribbon X Garawi	16.3	- 36.0*	- 38.1*	35.0	- 21.0	- 15.5
12	B.Ribbon X Ankolib	182.1**	71.0*	- 21.4	- 2.47	- 40.2*	- 52.0**
13	N 109 X S.70	284.2**	121.2*	- 38.1*	141.4**	47.5	- 27.4*
14	N 109 X S.186	372.1**	173.2**	- 26.5	111.4**	22.5	- 15.5
15	N 109 X Garawi	105.0**	7.02	3.39	56.2*	- 13.9	- 7.90
16	N 109 X Ankolib	144.7*	33.6	- 38.6*	5.33	- 40.2*	- 52.0**
17	Dale X S.70	168.1*	87.9	- 47.5**	88.6**	63.0*	- 19.8
18	Dale X S.186	220.0**	126.8*	- 39.0*	105.2**	56.0**	7.60
19	Dale X Garawi	116.9**	21.1	17.0	35.7	- 9.38	- 3.04
20	Dale X Ankolib	75.6	9.22	- 49.8**	63.9**	18.6	- 4.86
21	N 100 X S.70	170.6*	126.5*	- 36.7*	183.1**	116.7**	6.69
22	N 100 X S.186	243.5**	192.1**	- 21.4	43.1	- 1.32	- 31.9*
23	N 100 X Garawi	14.9	- 31.4	- 33.7*	7.76	- 33.0*	- 28.3*
24	N 100 X Ankolib	37.3	- 3.23	- 55.5**	- 13.7	- 42.8*	- 54.1**
25	Sugar Drip X S.70	160.8*	91.7	- 46.4**	83.8*	46.9	- 27.7*
26	Sugar Drip X S.186	322.2**	214.2**	- 15.5	129.6**	63.9**	13.1
27	Sugar Drip X Garawi	36.3	- 22.6	- 25.2	15.4	- 26.4*	- 21.3
28	Sugar Drip X Ankolib	75.6	12.9	- 48.1**	- 5.82	- 35.6*	- 48.3**
	Mean	143.2	66.3	-34.0	53.5	7.46	-24.5
	Range	- 29.7	-56.1	- 59.1	- 13.7	- 42.8	- 54.1

372.1	214.2	17.0	183.1	116.7	13.1

*, ** = significant at 0.05 and 0.01 probability level respectively

Table 30. Mean squares from line x tester analysis of variance for percentages of neutral detergent fiber (NDF), crude fiber (CF), crude protein (CP), Ash and ether extract (E.E) of 28 forage sorghum hybrids and their parents, grown at Shambat (2002)

Source of variation	d.f.	NDF	CF	CP	ASH	E.E.
		Mean Squares				
Rep	1	11.10 NS	45.57**	2.084 NS	4.228**	1.000**
Hybrid (H)	27	192.07**	18.33**	2.412**	3.061**	0.375**
Parent (P)	10	11.14 NS	14.26**	6.823**	3.300**	0.136 NS
P vs H	1	154.73**	53.64**	2.545*	7.010**	0.039 NS
Line (L)	6	316.14 NS	9.601 NS	3.059 NS	3.566 NS	0.092 NS
Tester (T)	3	160.81 NS	9.286 NS	0.286 NS	4.717 NS	0.705 NS
L x T	18	155.921**	22.74**	2.550**	2.616**	0.415**
Error	38	9.94	2.627	0.613	0.459	0.078
CV %		5.04	4.58	13.76	7.85	21.0

*, ** = significant at 0.05 and 0.01 probability level respectively
N.S. = non-significant at 0.05 probability level

Table 31. Percentage neutral detergent fiber (NDF), crude fiber (CF), crude protein (CP), Ash and ether extract (E.E) of forage sorghum hybrids and their parents, grown at Shambat (2002)

Entry	Hybrid		NDF	CF	CP	ASH	E.E.
			Percentage				
1	E-35-1	X S.70	70.0	32.5	4.65	8.06	1.23
2	E-35-1	X S.186	67.5	40.0	4.48	7.30	0.83
3	E-35-1	X Garawi	75.5	34.5	6.81	8.20	1.61
4	E-35-1	X Ankolib	66.5	38.0	5.49	10.22	1.20
5	Hastings	X S.70	57.0	31.5	7.26	9.40	0.80
6	Hastings	X S.186	37.0	37.0	6.38	7.80	0.80
7	Hastings	X Garawi	71.5	37.0	5.41	8.41	1.98
8	Hastings	X Ankolib	62.0	35.0	7.18	9.76	1.60
9	B.Ribbon	X S.70	67.5	36.5	5.83	8.46	2.00
10	B.Ribbon	X S.186	56.0	33.0	5.47	8.87	1.18
11	B.Ribbon	X Garawi	64.0	40.0	6.82	10.20	0.80
12	B.Ribbon	X Ankolib	56.5	34.5	6.29	11.20	1.18
13	N 109	X S.70	58.0	38.5	4.62	8.49	1.60
14	N 109	X S.186	60.0	31.0	5.28	7.16	0.81
15	N 109	X Garawi	60.0	32.0	5.49	8.64	1.20
16	N 109	X Ankolib	70.0	39.0	6.60	9.85	1.20
17	Dale	X S.70	34.5	34.5	6.38	8.62	0.82
18	Dale	X S.186	67.0	34.0	7.48	9.59	1.59
19	Dale	X Garawi	45.5	33.5	5.94	8.92	1.60
20	Dale	X Ankolib	57.5	32.0	3.17	8.10	1.60
21	N 100	X S.70	63.5	37.0	4.85	7.25	1.21
22	N 100	X S.186	62.5	33.0	6.29	7.38	0.79
23	N 100	X Garawi	65.0	27.5	3.35	7.78	1.20
24	N 100	X Ankolib	62.0	36.5	5.00	8.76	2.00
25	Sugar Drip	X S.70	59.5	31.5	4.87	12.70	1.20
26	Sugar Drip	X S.186	62.5	37.5	5.06	8.59	1.20
27	Sugar Drip	X Garawi	75.0	33.0	5.14	8.71	2.43
28	Sugar Drip	X Ankolib	72.5	36.0	4.47	8.51	1.21
		Mean hybrids	61.6	34.9	5.57	8.82	1.32
	Parents						
29	E-35-1	♀	60.0	37.0	6.85	8.10	1.20
30	Hastings	‘’	63.5	32.5	3.95	8.87	1.62
31	Blue Ribbon	‘’	65.5	39.0	7.11	8.21	1.58
32	N 109	‘’	64.0	36.0	8.13	9.30	1.61
33	Dale	‘’	63.0	37.2	3.65	7.12	1.41
34	N 100	‘’	65.5	33.5	5.00	6.19	1.21
35	Sugar Drip	‘’	67.0	36.0	5.96	7.41	1.20
36	S.70	♂	66.0	38.0	6.70	9.05	1.58
37	S.186	‘’	65.5	36.5	4.70	6.19	0.82
38	Garawi	‘’	63.5	42.5	9.42	9.96	1.60
39	Ankolib	‘’	69.0	35.5	4.26	9.28	1.20
		Mean parents	64.8	36.7	5.98	8.15	1.37
	Grand Mean		62.5	35.4	5.69	8.63	1.33
	S.E ±		2.23	1.15	0.55	0.48	0.20

Table 32. Estimates of general (GCA) and specific (SCA) combining ability effects in forage sorghum, for neutral detergent fiber (NDF), crude fiber (CF), crude protein (CP), Ash and ether extract (E.E), Shambat (2002)

Range (hybrids)	34.5-75.5	27.5-40.0	3.17-7.48	7.16-12.7	0.79-2.43
Range (parents)	60.0-69.0	32.5-42.5	3.65-9.42	6.19-9.96	0.82-1.62
LSD (0.05)	6.38	3.28	1.58	1.37	0.566
LSD (0.01)	8.55	4.40	2.12	1.84	0.758

*, ** = significantly different from zero at 0.05 and 0.01 probability level respectively.

Entry	Name	NDF	CF	CP	ASH	E.E.
	SCA (Hybrid)					
1	E-35-1 X S.70	3.196	-3.464*	-0.628	-0.563	0.061
2	E-35-1 X S.186	0.339	3.536*	-1.081	-0.425	-0.101
3	E-35-1 X Garawi	2.054	-0.821	1.460	-0.120	0.166
4	E-35-1 X Ankolib	-5.589	0.750	0.249	1.108	-0.126
5	Hastings X S.70	3.196	-3.339*	0.782	0.379	-0.448
6	Hastings X S.186	-17.161**	1.661	-0.381	-0.322	-0.205
7	Hastings X Garawi	11.054**	2.804	-1.140	-0.308	0.457
8	Hastings X Ankolib	2.911	-1.125	0.739	0.251	0.195
9	B.Ribbon X S.70	9.571**	0.786	-0.193	-1.401*	0.761**
10	B.Ribbon X S.186	-2.286	-3.214	-0.836	-0.092	0.179
11	B.Ribbon X Garawi	-0.571	4.929**	0.725	0.642	-0.719*
12	B.Ribbon X Ankolib	-6.714**	-2.500	0.304	0.851	-0.221
13	N 109 X S.70	-0.929	3.661*	-0.798	-0.223	0.448
14	N 109 X S.186	0.714	-4.339*	-0.421	-0.655	-0.105
15	N 109 X Garawi	-5.571	-2.196	0.000	0.230	-0.233
16	N 109 X Ankolib	5.786	2.875	1.219	0.648	-0.110
17	Dale X S.70	-13.554**	1.286	0.717	-0.366	-0.529
18	Dale X S.186	18.589**	0.286	1.534	1.503*	0.474
19	Dale X Garawi	-9.196**	0.929	0.205	0.237	-0.029
20	Dale X Ankolib	4.161	-2.500	-2.456**	-1.374*	0.084
21	N 100 X S.70	3.321	3.786	0.057	-0.721	-0.038
22	N 100 X S.186	1.964	-0.714	1.214	0.308	-0.225
23	N 100 X Garawi	-1.821	-5.071**	-1.515	0.112	-0.328
24	N 100 X Ankolib	-3.464	2.000	0.244	0.301	0.590*
25	Sugar Drip X S.70	-4.804	-2.714	0.064	2.894**	-0.256
26	Sugar Drip X S.186	-2.161	2.786	-0.029	-0.317	-0.018
27	Sugar Drip X Garawi	4.054	-0.571	0.263	-0.793	0.688*
28	Sugar Drip X Ankolib	2.911	0.500	-0.299	-1.784*	-0.413
	S.E.	2.230	1.148	0.554	0.479	0.197
	GCA Lines (Females)					
29	E-35-1	8.232*	1.393	-0.216	-0.374	-0.100
30	Hastings	-4.768*	0.268	0.984*	0.024	-0.021
31	Blue Ribon	-0.643	1.143	0.528	0.864*	-0.025
32	N 109	0.357	0.268	-0.076	-0.284	-0.116
33	DALE	-10.518**	-1.357	0.169	-0.011	0.085
34	N 100	1.607	-1.357	-0.701	-1.026*	-0.016
35	Sugar Drip	5.732*	-0.357	-0.689	0.809*	0.193
	S.E.	1.115	0.573	0.277	0.240	0.099
	GCA Testers (Males)					
36	S.70	-3.071*	-0.286	-0.079	0.178	-0.051
37	S.186	-2.714*	0.214	0.204	-0.720*	-0.289*
38	Garawi	3.571*	-0.929	-0.008	-0.125	0.230
39	Ankolib	2.214	1.000	-0.116	0.667*	0.111

Table 33. Heterosis over mid-parent for neutral detergent fiber (NDF), crude fiber (CF), crude protein (CP), Ash and ether extract (E.E) of forage sorghum hybrids and their parents, Shambat (2002)

S.E.	0.843	0.423	0.209	0.181	0.075

*, ** = significant at 0.05 and 0.01 probability level respectively.

Table 33. Heterosis over mid-parent for neutral detergent fiber (NDF), crude fiber (CF), crude protein (CP), Ash and ether extract (E.E) of forage sorghum hybrids and their parents, Shambat (2002)

Entry	Hybrid	NDF	CF	CP	ASH	E.E.
		Percentage				
1	E-35-1 X S.70	11.1*	-13.3**	-31.4**	-6.01	-11.5
2	E-35-1 X S.186	7.57	8.84	-22.4	2.17	-17.8
3	E-35-1 X Garawi	22.3**	-13.2**	-16.3	-9.19	15.0
4	E-35-1 X Ankolib	3.10	4.83	-1.17	17.6*	0.00
5	Hastings X S.70	-12.0*	-10.6*	36.3*	4.91	-50.0**
6	Hastings X S.186	-42.6**	7.25	47.5*	3.59	-34.4
7	Hastings X Garawi	12.6**	-1.33	-19.1	-10.7	23.0
8	Hastings X Ankolib	-6.42	2.94	74.9**	7.55	13.5
9	B.Ribbon X S.70	2.66	-5.19	-15.6	-1.97	26.6
10	B.Ribbon X S.186	-14.5**	-12.6**	-7.37	23.2*	-1.67
11	B.Ribbon X Garawi	-0.78	-1.84	-17.5	12.3	-49.7**
12	B.Ribbon X Ankolib	-16.0**	-7.38	10.6	28.1**	-15.1
13	N 109 X S.70	-10.8*	4.05	-37.7**	-7.47	0.31
14	N 109 X S.186	-7.34	-14.5**	-17.7	-7.55	-33.3
15	N 109 X Garawi	-5.88	-18.5**	-37.4**	-10.3	-25.2
16	N 109 X Ankolib	5.26	9.09	6.54	6.03	-14.6
17	Dale X S.70	-47.3**	-8.24	23.3	6.62	-45.2*
18	Dale X S.186	4.28	-7.73	79.2**	44.1**	42.6
19	Dale X Garawi	-28.1**	-15.9**	-9.10	4.45	6.31
20	Dale X Ankolib	-12.9*	-12.0*	-19.9	-1.22	22.6
21	N 100 X S.70	-3.42	3.50	-17.1	-4.86	-13.3
22	N 100 X S.186	-4.58	-5.71	29.69	19.2	-22.2
23	N 100 X Garawi	0.78	-27.6**	-53.5**	-3.65	-14.6
24	N 100 X Ankolib	-7.81	5.80	7.99	13.3	66.0**
25	Sugar Drip X S.70	-10.5*	-14.9**	-23.1	54.3**	-13.67
26	Sugar Drip X S.186	-5.66	3.45	-5.07	26.3*	18.81
27	Sugar Drip X Garawi	14.9**	-15.9**	-33.2	0.29	73.6**
28	Sugar Drip X Ankolib	6.62	0.70	-12.5	1.98	0.83

Table 34. Heterosis over better-parent for neutral detergent fiber (NDF), crude fiber (CF), crude protein (CP), ash and ether extract (E.E) of forage sorghum hybrids and their parents, Shambat (2002)

	NDF	CF	CP	ASH	E.E.
Mean	-5.19	-5.57	-2.9	7.61	-1.9
Range	-47.3	-27.6	-53.5	-10.7	-49.7
	22.3	9.09	79.2	[illegible]	73.6

*, ** = significant at 0.05 and 0.01 probability level respectively

Entry	Hybrid	NDF	CF	CP	ASH	E.E.
		Percentage				
1	E-35-1 X S.70	16.7**	-12.2**	-32.1**	-10.9	-22.2
2	E-35-1 X S.186	12.5*	9.59*	-34.6**	-9.88	-30.8
3	E-35-1 X Garawi	25.8**	-6.76	-27.7**	-17.7*	0.63
4	E-35-1 X Ankolib	10.8*	7.04	-19.9	10.1	0.00
5	Hastings X S.70	-10.2*	-3.08	8.36	3.87	-50.6**
6	Hastings X S.186	-41.7**	13.9**	35.7*	-12.1	-50.6**
7	Hastings X Garawi	12.6*	13.9**	-42.6**	-15.6*	22.2
8	Hastings X Ankolib	-2.36	7.69	68.5**	5.17	-1.23
9	B.Ribbon X S.70	3.05	-3.95	-18.00	-6.52	26.6
10	B.Ribbon X S.186	-14.5**	-9.59*	-23.1*	8.04	-25.3
11	B.Ribbon X Garawi	0.79	2.56	-27.6**	2.41	-50.0**
12	B.Ribbon X Ankolib	-13.7**	-2.82	-11.5	20.7**	-25.3
13	N 109 X S.70	-9.38	6.94	-43.2**	-8.71	-0.62
14	N 109 X S.186	-6.25	-13.9**	-35.1**	-23.0**	-49.7**
15	N 109 X Garawi	-5.51	-11.1*	-41.7**	-13.3	-25.5
16	N 109 X Ankolib	9.38	9.86*	-18.8	5.91	-25.5
17	Dale X S.70	-46.0**	-7.26	-4.78	-4.75	-48.1**
18	Dale X S.186	6.35	-6.85	59.2**	34.7**	12.8
19	Dale X Garawi	-27.8**	-9.95*	-36.9**	-10.4	0.00
20	Dale X Ankolib	-8.73	-9.86*	-25.6	-12.7	13.5
21	N 100 X S.70	-3.05	10.5*	-27.6*	-19.89*	-23.4
22	N 100 X S.186	-4.58	-1.49	25.8	19.22	-34.7
23	N 100 X Garawi	2.36	-17.9**	-64.4**	-21.9**	-25.0
24	N 100 X Ankolib	-5.34	8.96	0.00	-5.60	65.3**
25	Sugar Drip X S.70	-9.85*	-12.5**	-27.3*	40.3**	-24.1
26	Sugar Drip X S.186	-4.58	4.17	-15.1	15.9	0.00
27	Sugar Drip X Garawi	18.1**	-8.33	-45.4**	-12.6	51.9**
28	Sugar Drip X Ankolib	8.21	1.41	-25.0	-8.30	0.83
	Mean	-3.11	-1.47	-16.09	-1.69	-11.39
	Range	-46.0	-17.9	-64.4	-23.0	-50.6
		25.8	13.9	68.5	40.3	65.3

5.0 Discussions

5.1 Agronomic performance

Combined analysis of variance (Tables 2 and 3) showed that the mean squares for entries were large and highly significant for all characters studied, indicating that considerable portion of the variability observed was due to entries. The entry x year interaction unlike that with location was highly significant for all characters, suggesting the need for testing over years rather than over locations.

A number of hybrids excelled the parental lines and the commercial hybrid Panar 888 in many forage attributes, with some of them showing significant improvement in forage yield and other desirable forage traits. The multiple range test performed for forage yield (Tables 8 and 9) showed that four experimental hybrids significantly out-yielded the commercial hybrid Panar 888 and the male parents derived from the traditional cultivar Abu Sab'in (S.70 and S.186). Three of these hybrids involved the female parent E-35-1 with S.70, S.186, and Garawi. The other hybrid was Dale x S.70. The four hybrids performed consistently across years and locations (Tables 4, 5, 6 and 7). As indicated by Tables 10 and 11, the increase in forage yield attained by these hybrids over Panar 888 could be mainly attributed to the increase in stem diameter and plant height. Both characters were reported to be the main determinants for forage yields in sorghum (Dharampal and Singh, 1973; Ibrahim and Orfi, 1996). On the other hand, the commercial hybrid Panar 888 excelled the four hybrids in stem diameter (fine stem), leaf to stem ratio, tillering and regrowth. Such characters meet the requirements of grazing and hay making systems predominating in countries other than Sudan. The green chopping, the prevailing system in the Sudan is not largely adopted in South Africa, where Panar 888 had been developed. One of the four hybrids, namely, Dale x S.70 was significantly earlier in flowering than Panar 888. Earliness is a desirable character under forage production system in the Sudan. Hybrids less productive than Panar 888, but with comparable or sometimes better values for regrowth and leaf to stem ratio could be noticed (Tables 10 and 11) indicating the potential of the studied material in improving these traits.

Some of the four hybrids were also significantly better than Abu Sab'in selections in leaf to stem ratio, tillering and regrowth especially in the first year (Tables 10 and 11). These results point to the possibility of developing hybrid excelling the traditional cultivar Abu Sab'in in yield and other desirable forage traits. However, earliness may be the only exception. When breeding for forage improvement, the choice for developing late or early flowering variety is largely determined by the system adopted for forage production. Late flowering types are usually preferred under grazing system to allow for prolonged utilization of the pasture before the nutritive value is lowered by flowering. On the other hand, early flowering types are desirable under green chopping system particularly when the forage is grown as a cash crop, which is likely the case in the Sudan. In the studied material, the local cultivar Abu Sab'in is represented by two selections viz, the early flowering Rubatab type (S. 186) and the late flowering Alyab type (S. 70). All the hybrids out-yielding both Abu Sab'in selections were later in flowering especially when compared to S. 186 (Rubatab type). Nevertheless, one of these hybrids, namely, Dale x S.70 was earlier in flowering than S.70 (Alyab type). This hybrid seems to depict a good compromise between forage yield and earliness. The hybrid Hastings x S.70 may be the second choice in this regard although it was not significantly out-yielding Panar 888. Combining all desirable traits in one hybrid is not an easy task due to unfavorable association encountered sometimes between characters. Early flowering in many instances was found to be adversely associated with forage yield. The data presented by Ross, *et al.* (1983) for correlation among forage traits indicated that late flowering favors high stem and leaf yields. However, in this context, the results presented could be more valued if we consider that the superiority of hybrids is tested against improved versions of the traditional cultivar

Abu Sab'in and the hybrid Panar 888, which was one of the earliest commercial hybrids (Mohammed, 2001).

In conclusion, the data presented for forage yield clearly demonstrate the possibility of developing local hybrids excelling the introduced hybrids and the traditional cultivar Abu Sab'in. The potential exists for developing hybrids with increased forage yield coupled with improved regrowth, tillering and leaf to stem ratio especially when referring to the local cultivar Abu Sab'in. However, improvement in earliness is not clearly manifested by this study. More research efforts are therefore needed, if we decided to include earliness as a desirable trait under the local production system.

5.2 Combining ability

The entry source of variation was partitioned to evaluate the significance of variation among different subgroups of entries. The data presented in Tables 12 and 14 point to the high degree of genetic variability existing among parents and hybrids for all characters studied. As indicated by the magnitude of mean squares, the variability among hybrids was less than that among parents for all characters. The contrast of parents vs hybrids was sizable and highly significant for all characters, pointing to the potential of heterotic effects among hybrids (Tables 12 and 14). The interaction of hybrids and their parents with years and locations indicate that, for all characters, both groups performed consistently over locations, but not over years. Second order interaction with hybrids and their parents were low and insignificant for all characters, however, mean squares of hybrids were apparently lower in magnitude, pointing to the relative consistency of hybrids over environment compared to their parents.

Table 13 shows that the variability among lines (females) and testers (males) was high, as indicated by the highly significant mean squares for the characters studied. However, mean squares from single line x tester analysis for tillering and regrowth (Table 14) indicated that the variability among lines for these characters was low compared to testers. Generally, the magnitude of mean squares in both analysis (Tables 13 and 14) indicate that testers were more variable than lines for most characters. This is expected since the testers represent diverse groups of forage sorghum (grass, sweet and grain forage sorghums), whereas the lines are largely representing one group (sweet sorghum). The interaction of lines with testers was highly significant for most characters indicating the presence of specific effects. The low and insignificant interactions of lines and testers with location noticed for all characters in Table 13 indicate that both groups performed consistently across locations. The performance of testers across years, with few exceptions, was consistent. On the other hand, the lines performed inconsistently across years for days to flowering, plant height and stem diameter and consistently with regard to forage yield and leaf to stem ratio.

Given that testers are more genetically diverse, more significant GCA cases were therefore noted among testers compared to lines (Tables 15 through 18). The insignificant GCA effects noted for plant height (Table 16) might be attributed to the high interaction of lines and testers with years observed for this character (Tables 13). The mean squares of lines for leaf to stem ratio though significant, was apparently low, pointing to the little variability among lines for this character (Table 13). This might explain the absence of significant GCA effects for leaf to stem ratio among lines.

General and Specific combining ability effects : The data presented in Table 15 indicate that E-35-1 from lines and S.70 from testers appear to be the best general combiners for green and dry forage yield and may be expected to do well in hybrid combinations with other parents. The female parent E-35-1 was involved in 3 of the 4 top yielding hybrids (Tables 8 and 9). Unfortunately, it turned to be the poorest combiner for earliness and might be responsible for transmitting lateness in flowering to its hybrids. As discussed earlier, lateness is an undesirable character under the local forage production system. Further-more, E-35-1 and S. 70 were poor general combiners for leaf to stem ratio, especially the latter. Leaf to stem ratio was considered by many workers (e.g. Chacon and Stobbs, 1976; Chacon et al, 1978; Forbes and Colman, 1993) as being essential in determining forage quality, diet selection and forage intake. Other promising general combiners for forage yield include Ankolib from testers and Dale from lines. Although the male parent Ankolib was a poor general combiner for earliness, yet it was a good combiner for leaf to stem ratio. On the other hand, the female parent Dale possessed medium GCA effects for earliness and leaf to stem ratio and was the best general combiner among lines for tillering and regrowth. In addition, as indicated by Tables 8 and 9, Dale was involved in one of the four top yielding hybrids. The hybrid Dale x S.70 was the earliest among the top yielding hybrids and at the same time depicted a good performance for other desirable traits. Therefore, although it ranked third in general effects for yield, Dale could be regarded as the best choice for a line that possesses acceptable GCA effect for yield and at the same time maintains considerable general effects for other desirable traits.

Many significant GCA cases were detected for days to flower compared to other characters. This could be attributed to the high level of genetic variability observed for this character among the material studied. The best general combiners for earliness were, Blue Ribbon, N 109 from lines and

S.186, Garawi from testers. Garawi (the traditional Sudan grass cultivar) was also the best general combiner for tillering, regrowth and leaf to stem ratio. Unfortunately, it was the poorest general combiner for forage yield among testers. The data presented in Table 15 indicate that most of the hybrids in which Garawi was involved, ranked low in forage yield and most of them showing a yield rank ranging from 24 to 31.

Number of tillers per plant was the only character that showed insignificant SCA values. This was further explained by the low and insignificant line x tester interaction observed for this character across all years and locations (Table 14). Most of the top yielding hybrids showed significant SCA values for forage yield, indicating the involvement of specific effect in the expression of yield of these hybrids. However, ranking of hybrid's yields along with their respective SCA effects (Table 15) showed that the highest mean values for a trait did not necessarily indicate significant SCA effects or vice versa. For example the hybrid E-35-1 x S. 70 ranked first in forage yield, but it showed negative SCA value for this character. Thus, since E-35-1 and S. 70 were the best general combiners for forage yield, the outstanding performance of their hybrid was mainly due to general effects. Such patterns of combining ability effects were encountered by Ross *et al*. (1983) and Satyanarayana (1998). The 3 top yielding hybrids involving E-35-1 showed undesirable specific effect for days to flower. E-35-1 showed the highest general effect for lateness. These results confirm our previous concerns that this line was responsible from transmitting late flowering to its progenies.

Relative importance of general and Specific effects : The results presented in this study indicate that, with the exception of number of tillers per plant, both general and specific effects were important in the expression of all characters, with general effects being more important than the specific ones for characters other than plant height and regrowth (Tables 19 and 20). Consequently, with the exception of number of tillers per plant, both additive and non-additive gene actions are expected to be important in the expression of all characters, with the preponderance of additive gene actions for days to flower, forage yield, stem diameter, leaf to stem ratio and non-additive actions for plant height and regrowth. The magnitude of GCA/SCA variance ratio for number of days to flower was comparatively sizable, indicating the predominance of additive gene action; however, the specific effects were also highly significant, suggesting the involvement of non-additive effects in controlling this character.

With regard to number of tillers per plant, the insignificant specific effects coupled with the high GCA/SCA variance ratio noticed for this character in most years and locations, indicate that it was mainly under the control of additive gene actions (Table 20).

For forage yield, these results were in agreement with those reported by Blum (1968), Gupta *et al.* (1976) and Dangi *et al.* (1980); and disagree with the results obtained by Sanghi and Monpara (1981) and Gupta and Paliwal (1981). The data presented by Blum (1968) showed that GCA variance was 20.5 times greater than SCA variance for forage yield. Gupta *et al.* (1976) reported 2 to 12 GCA/SCA variance ratio for the same character. In this study the magnitude of GCA/SCA variance ratio was much lower (< 4) indicating the relative importance of non-additive gene action in controlling forage yield.

The results shown by this study for days to flower, agree with those of Liang (1967), Bijapur (1980) and Meng *et al.* (1998) and disagree with those of Kukadia and Sinhania (1980) and Sanghi and Monpara (1981). The results obtained in this study agree with those of Sanghi and Monpara (1981) for number of tillers per plant; Kirby and Atkins (1968) for stem diameter, and disagree with the results reported by Kukadia and Sinhania (1980) for leaf to stem ratio.

The results presented in Tables 19 and 20 indicate that non-additive gene actions were more important than additive actions in controlling plant height and regrowth. For plant height, this was in accordance with Sanghi and Monpara (1981) but it was not in agreement with those of many workers (e.g. Kirby and Atkins, 1968; Shankaregowda *et al.*, 1972a; Singhania, 1980 and Meng *et al.*, 1998). With respect to regrowth, agreeing or disagreeing results could not be traced in the literature.

The apparently low interaction of GCA variance with years as compared to those of SCA variance indicate that general effects are more stable over years compared to specific effects (Table 19). Kambal and Webster (1965) studying general and specific effects in grain sorghum reported similar results. On the other hand, evaluation of the relative importance of locations and years effects showed that interactions of genetic effects with years were more pronounced than those with locations. Given the low and insignificant second order interaction, and considering the costs of adding locations, it can be postulated that, testing over years at one location with increased number of replications, might be of value for combining ability evaluation. Rasmusson and Glass (1967) studying genetic and environmental variability in barley arrived to similar conclusion.

Contribution of lines, testers and line x tester to total variance : The contributions of either lines or testers to the total variance of crosses were higher than their respective line x tester interaction for characters other than plant height and regrowth. These results reflect the previous findings that general effects were more important than specific ones in the expression of these characters (Tables 21 and 22). Although the variability observed among testers was in most cases higher than that among lines, yet the data presented indicate that the contribution of lines to the total variance was greater than that of testers in 4 characters, whereas the contribution of testers was greater than that of lines in only two characters. Both parental groups showed similar contribution with respect to the other two characters. These results indicate that high variability among a parental group did not necessarily imply high contribution of that group to the total variance of the crosses. This is particularly true for days to flower, plant height and stem diameter, where the variability observed among lines and testers for these characters (Table 13) are not matching their respective contributions to the total variance.

5.3 Heterosis

Some of the results from heterosis study reflect the previous findings of specific combining ability effects. With few exceptions, significant desirable heterosis estimates were encountered for all characters, especially for average heterosis and heterobeltiosis, indicating that opportunities exist for exploiting heterosis in forage improvement.

Sedcole (1981) defined heterosis as the increased vigor of F1 hybrid over the mean of its parents or over the better parent. Kambal and Abu-El-

Gasim, 1975 stated that the increase over the better parent is more important as it implies the improvement of yield and other desirable traits over the existing maxima. The results presented in this study indicate that significant gains in forage yield over mid-parent and better parents were exhibited by many hybrids. Five hybrids showed significant standard heterosis in the positive direction for GMY. These results agreed with those reported for average heterosis by Paroda *et al.* (1972), Chauhan and Sing (1973) and Scapim *et al.* (1998). Although the magnitudes of heterosis shown by this study were not striking (mostly below unity) compared to those reported by two of these workers, however, the superiority over the existing maxima in forage yield has been clearly demonstrated by some hybrids, namely, the hybrids involving the line E-35-1 with the testers : S. 70, S. 186, and Garawi; in addition to the hybrids : Dale x S.70, Hastings x S. 70 and Sugar Drip x Ankolib (Table 23). This indicates further the feasibility of utilizing heterosis in developing hybrids better in forage yield than the top yielding local cultivars and the introduced hybrids. However, most of these hybrids showed low or negative heterosis for some desirable traits. Nonetheless, with the exception of earliness, the other traits are not presently crucial for forage yield under the present system of forage production in the Sudan. Despite of what has been mentioned, one of the top yielding hybrids (Dale x S.70) showed desirable heterosis for earliness over Abu Sab'in (Alyab type) and the hybrid Panar 888.

The greatest average heterosis and heterobeltiosis for forage yield were displayed by the hybrids involving the tester Ankolib with the lines Sugar Drip and Blue Ribbon. Both hybrids showed highly significant specific effect and were among the best ten yielding hybrids. Given that their parents were generally low in GCA, thus, the improved yields noticed for these hybrids were largely due to non-additive gene effects.

Generally, the means of average heterosis and heterobeltiosis indicate that the general trend for heterotic effects were towards increased forage yield, plant height, stem thickness, tillering, regrowth and reduced leaf to stem ratio. The negative heterosis for leaf to stem ratio could be attributed to the increased stem diameter of hybrids and the high values incurred by female parents for this character. For days to flower, the general trend for heterotic effect with regard to average heterosis was towards earliness whereas for heterobeltiosis it was towards lateness. However, some of the hybrids showed equal or better earliness compared to their earliest parents.

The results presented for plant height and earliness in flowering were in agreement with those reported by Kambal and Webster (1966), Kirby and Atkins (1968) and Shankaregowda *et al.* (1972b) for the two characters; and Toure *et al.* (1996) for earliness in flowering. With respect to tillering, the results presented were in accordance with those of Paroda *et al.* (1972). For stem diameter, the results agreed with those of Kirby and Atkins (1968), Kambal and Abu-El-Gasim (1976) and disagreed with those of Chauhan and Singh (1973).

5.4 Proximate analysis for forage quality traits

General performance : The results of the quality traits study should be cautiously considered since they were based on data from single experiment. The highly significant differences observed for all quality traits indicate that most of the variability observed was due to entries. However, most of these variations were mainly due to hybrids as both lines and testers exhibited insignificant mean squares for all characters. The mean squares of lines for crude protein (CP), was more than ten times greater than that for testers, indicating that lines were more variable than testers for this character.

The seemingly low levels of CP or high levels of neutral detergent fiber (NDF) and crude fiber (CF) obtained in this study are expected because the samples were taken two weeks after flowering to simulate the farmers' general practice of harvesting forage sorghum. One of the well established facts in forage quality is the decrease in CP and increase in fiber content as the crop matures. The percentages of CP obtained for hybrids in this study (Table 31) were comparable to those reported by Jones and Read (1989) for forage sorghum hybrids harvested at dough stage with a mean value of 5.36 % and a range of 4.29 % to 7.36 %. On the other hand, the NDF values for hybrids averaged slightly higher (61.6 %) than those reported by the Kansas Crop Performance Tests (2003) that averaged 59.6 %.

The NDF measures the intake potential. Dry matter intake is negatively related to NDF content in high producing diary cows (Mertens, 1987) and was also found to be negatively related to digestibility (Argillier *et al.*, 2000). In this study, the proximate analysis of NDF, CF and Ash indicate that the overall nutritive value of hybrids was better compared to their parents with regard to these characters. The mean performance of hybrids for CP was slightly lower compared to their parents. Given that the hybrids were superior in yield, the low performance in CP observed for hybrids compared to their parents could be explained by the negative relationship usually observed between the two characters (Ross, *et al.* 1983, Read and Jones, 1985; Jones, 1989; Sanderson *et al.*, 1993). In spite of that, the total effect was towards more protein being provided by hybrids because they were better in intake compared to their parents.

The hybrid Dale x S. 70 merits especial consideration. In addition to its remarkable agronomic performance, it showed strikingly low value for

NDF and was fairly high in crude protein. Similar performance was also shown by the hybrid Hastings x S. 70. In contrast, the other top yielding hybrids, especially those involving E-35-1 were generally poor in intake potential and most of them have low CP percentages.

Combining ability and heterosis : The absence or low occurrence of significant GCA effects for crude fiber (CF), crude protein (CP) and ether extract (E.E.) could be attributed to the lack of variability among both lines and testers for these characters.

Dale from lines and S. 70 from testers were the best general combiners for NDF followed by the line Hastings and the tester S. 186. Other good general combiners from lines include : Hastings for crude protein, Blue Ribbon and Sugar Drip for Ash. With regard to testers, Ankolib showed good general combining ability for Ash.

The hybrid Dale x S. 70 revealed highly significant desirable specific effect for NDF. Since the parents involved in this hybrid were good general combiners for NDF, it can be stated that general beside specific effects were responsible from its outstanding performance with regard to this character.

Although the means of both types of heterosis are not impressive for all characters, yet it is interesting to note that most of the hybrids with good performance for a quality trait displayed significant and reasonable heterosis values for that trait, indicating that heterosis breeding might be rewarding in improving such traits. In conclusion, although depending on data from single experiment may sometimes lead to erroneous assumptions; the results emerging from this study were encouraging and deserve further investigations.

5.5 Promising breeding materials

Some promising breeding materials have emerged from this study. The line Dale seemed to receive the top priority as it maintained desirable GCA effects for many characters including quality traits. E-35-1 could be the other choice from lines. It was only chosen for its distinguished general combining ability for forage yield. The major problem with E-35-1 was its high GCA for lateness in flowering which is undesirable under the present production system. However, economic evaluation may validate the utility of this line and its progenies may find their way to highly specialized animal-products sector, where lateness in flowering is not a major problem. From testers, S. 70 (Abu Sab'in) of Alyab type was promising general combiner for forage yield, NDF and has acceptable GCA effect for earliness. With regard to yield-related traits, Blue Ribbon from lines and

Garawi from testers were promising general combiner for earliness. Garawi was also a promising general combiner for regrowth and tillering. It is a highly heterogeneous cultivar and its GCA for forage yield might be improved by selection.

The studies carried for agronomic and quality traits, revealed that some hybrids can be identified as candidates. Of these the hybrid Dale x S. 70 was the most promising. In addition of being significantly out-yielding the parental material and the commercial hybrid Panar 888, it was also the best among hybrids for most quality traits and showed acceptable record for earliness, leaf to stem ratio, tillering and regrowth. The hybrid Hastings x S. 70 was the second candidate. It was higher in yield than Panar 888 but not significantly different from it. However, it was better than Dale x S. 70 in earliness and performed similar to it in other aspects. From the top-yielding E-35-1 family, two hybrids with better earliness were chosen as candidates. These were E-35-1 x S. 186 and E-35-1 x Garawi. The agronomic performance as well as the feeding value of the four chosen hybrids should be evaluated in the farmers' fields using traditional cultivars and commercial hybrids as checks. Economic assessment and farmers' opinion should be involved in the evaluation process.

5.6 Recommendations for future research :

The GCA in a crop like sorghum is important because it is of fixable nature. Characters like days to flower and number of tillers per plant were predominately controlled by additive genes; therefore selection in early generations will be effective in their improvement. On the other hand, both additive and non-additive effects were important in controlling forage yield, stem diameter and leaf to stem ratio. In such situations, reciprocal recurrent selection is usually suggested because it permits simultaneous exploitation of both general and specific effects (Singh and Narayanan, 1993). This breeding technique has been recently adapted for crops like sorghum (Brengman, 1995) where mass genetic recombination is facilitated by the use of the dominant fertility restoration gene ‘Rf_1’ in A_1 cytoplasm. However, such system will not work under the A3 cytoplasm due to the lack of genes that restore fertility. Nonetheless, the chance to capitalize on heterotic effects still exists for forage yield since appreciable non-additive effects were indicated by the highly significant mean squares observed for SCA and parents vs hybrids, in addition to the sizable and significant average heterosis and heterobeltiosis values. As pointed by Azhar *et al.* (1998) the occurrence of over mid-parent heterosis is due to genes acting non-additively whereas manifestation of heterobeltiosis is due to genes with over-dominance. Heterosis breeding is therefore could be effective in improving forage yield either through direct selection among hybrids for high forage yield, or by indirect selection for plant height (tall plants). On the other hand, specific effects for regrowth and leaf to stem ratio though significant, the magnitude of heterosis was either not impressive (for regrowth) or almost negative (for leaf to stem ratio) indicating that the chance is limited for improving these characters thorough heterosis breeding. This is especially true for leaf to stem ratio. It seems that the improvement of these characters requires a selection program based on more genetically diverse material with increased number of lines, where the chance for detecting desirable genes is more frequent. Selection for both characters needs to be delayed to later generations to allow for a decrease in dominance and their interactions. When a considerable portion of desirable genes are fixed or homozygous, breeding procedures to utilize non-additive effects can be employed.

Wide range of variability in sorghum is known to exist in Sudan (Yasin, 1978). In this study, introduced lines sterilized in A3 cytoplasm were used as females to develop exotic x local hybrids. Although the exotic material showed good contribution to the total variability noted among crosses, yet they were found to be largely responsible for transmitting some undesirable traits to their progenies, e.g. lateness in flowering. From our own field experience, forage growers are highly concerned about the duration taken by a variety to reach harvesting time. Earliness and other traits adapted to local conditions could be easily extracted from the variability existing among local material. Therefore, local x local hybrid should be seriously considered in future breeding programs. This in turn necessitates the need for male-sterilizing the local stocks. A3 cytoplasm maintains sterility in most genetic-backgrounds (Dahlberg and Madera-Torres, 1997) and seems to be the most appropriate sterility source due to its efficiency in male-sterilizing a large number of diverse genetic stocks. Preliminary selection within local stocks should be done first to eliminate undesirable traits or to include some easily inherited desirable traits like juiciness.

7.0 Appendices

Appendix 1. Animal flows to Khartoum State (2003)

Animal	Settled animals	Incoming animals
Cattle	204 000	300 000
Sheep	424 000	2000 000
Goats	617 000	300 000
Camels	5 400	5 000
Total	1 250 400	2 605 000

Source: Dr. Lo'ai Osman Hashim.The present status of Agriculture in Khartoum state (in Arabic). General Director, Ministry of Agriculture and Animal Wealth, Khartoum State.

Appendix 2. Forage production (1000 metric ton) in relation to other crops in Khartoum State (2003)

Crop	Production	Demand	Difference	Forage Gap (percentage)
Forage crops	1 378	2 187	- 809	37
Vegetables	1 118	663	+455	
Fruits	138	410	- 272	

Source: Dr. Lo'ai Osman Hashim.The present status of Agriculture in Khartoum state (in Arabic). General Director, Ministry of Agriculture and Animal Wealth, Khartoum State. (rearranged)

Appendix 3. The 29 forage sorghum genetic stocks in A3 cytoplasm

No.	Genetic stock	Recurrent parent	Cytoplasm source	Backcross generation
1	A3N149	Rox Orange	A3Tx398	BC4
2	A3N150	Brawley	A3Tx398	BC4
3	A3N151	Dale	A3Tx398	BC4
4	A3N152	Kansas Collier	A3Tx398	BC4
5	A3N153	Wary	A3Tx398	BC4
6	A3N154	Sugar Drip	A3Tx398	BC4
7	A3N155	Waconia-L	A3Tx398	BC4
8	A3N156	N98 (short selection)	A3Tx398	BC4
9	A3N157	N98 (tall selection)	A3Tx398	BC4
10	A3N158	N99	A3Tx398	BC4
11	A3N159	N100	A3Tx398	BC4
12	A3N160	EL-ES	A3Tx398	BC4
13	A3N161	Ellis	A3Tx398	BC4
14	A3N162	Fremont	A3Tx398	BC4
15	A3N163	Atlas	A3Tx398	BC4
16	A3N164	Early Hegari-Sart	A3Tx398	BC4
17	A3N165	Red X	A3Tx398	BC4
18	A3N166	Blue Ribbon	A3Tx398	BC4
19	A3N167	Colman	A3Tx398	BC4
20	A3N168	Hastings	A3Tx398	BC4
21	A3N169	E-35-1	A3Tx430	BC4
22	A3N170	IS2729	A3Tx430	BC5
23	A3N171	KS5	A3Tx398	BC4
24	A3N172	N108	A3Tx398	BC4
25	A3N173	N109	A3Tx398	BC4
26	A3N174	N110	A3Tx398	BC4
27	A3N175	N111	A3Tx398	BC4
28	A3N176	Early Sumac	A3Tx398	BC4
29	A3N177	Spanish Broomcorn	A3Tx398	BC4

Appendix 4. Agronomic performance and some morphological characteristics of 29 introduced sweet sorghum genotypes and the local check Ankolib grown at Shambat, 2001

Genotype	Plant ht (CM)	Days to flower	Stem Diam (CM)	Seed yielding ability ¶	Pericarp color	Mid-rib color (juiciness)
1-Fremont	158	45	1.15	M	Brown	G #
2-N98 "tall selection"	195	54	1.4	G	Brown	"
3-N99	169	47	0.9	M	Brown	"
4-Ellis	162	48	1.3	P	White	"
5-Ks5	123	47	1.2	M	Brown	"
6-Blue Ribbon	214	52	1.25	G	Brown	"
7-Early hegari-sart	131	56	1.5	G	White	"
8-N108	175	58	1.2	M	Tan	"
9-Early Sumac	207	53	1.5	P	Brown	"
10-Sugar drip	196	61	1.35	G	Brown	"
11-N98 "Short selection"	116	52	1.1	G	Brown	"
12-Brawley	207	54	1.2	P	Brown	"
13-EL-ES	195	50	1.05	P	White	"
14-N100	201	58	1.5	G	Brown	"
15-Red X	183	51	1.4	P	Brown	"
16-Atlas	224	59	1.35	G	White	"
17-Rox orange	195	51	1.15	M	Brown	"
18-Hastings	236	58	1.3	G	Brown	"
19-Waconia-L	158	48	1.25	M	Brown	"
20-Colman	184	54	1.4	M	Brown	"
21-B. Span. Broom corn	233	51	1.9	P	Brown	W @
22-IS2729	111	65	1.5	M	Brown	"
23-N109	127	58	1.35	G	White	G
24-Wary	203	54	1.25	M	Brown	"
25-N110	170	47	1.35	M	Brown	"
26-Dale	245	68	1.8	M	Brown	"
27-Kansas collies	181	55	1.1	M	Brown	"
28-E-35-1	163	85	1.75	G	White	"
29-N111	148	46	1.35	P	Brown	"
30-Ankolib (local check)	170	67	1.5	M	Brown	"
Mean	179	55	1.34			
SE ±	9.66	3.0	0.154			

G = Green (Juicy), @ W = White (Non-juicy)

¶: Based on head size, G, M and P denote good medium and poor yielding ability respectively

Appendix 5. Monthly means maximum (Max) and minimum (Min) temperatures (C^o), rain fall (mm) and percentage relative humidity (R.H.) during the growing seasons (2002-2003) as recorded at Shambat Meteorological Observatory

	Monthly means (2002)				Monthly means (2003)			
	Temp		R.H.	Total rain fall	Temp		R.H.	Total rain fall
	Max	Min			Max	Min		
Month								
June	41.9	26.2	23.0	0.1	40.9	27.0	33.0	6.0
July	40.5	26.8	36.0	9.0	37.3	25.2	49.0	41.1
Aug.	37.3	25.2	48.0	88.0	35.8	25.3	58.0	74.0
Sept.	39.6	26.1	42.0	15.0	38.4	25.2	45.0	12.9
Oct.	39.7	24.8	30.0	6.1	39.9	23.9	31.0	3.4

6.0 -Literature Cited

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