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Emergence and Seedling Characteristics of Maize Native to the Southwestern US

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Abstract

Locally adapted maize landraces, which are associated with Native American groups, were traditionally planted deeply, reportedly up to 45 cm deep. Crop resources such as these should be evaluated for possible use in future sustainable farming practices. Cold temperatures often delay maize (*Zea mays* L.) planting in the Corn Belt, possibly reducing yield potential, and spring frost and hail can damage early plantings. If producers could plant deeper and earlier in the spring, the planting season period could be extended and the potential for frost damage reduced because the growing point would be insulated below the soil surface for a longer period of time. The emergence capabilities of eleven Native American landraces were evaluated at various planting depths and compared to one Corn Belt line, BSSS-53. Emergence from depths between 5 and 45 cm was evaluated in a growth chamber study. Seedling dry matter partitioning and morphological characteristics were also examined. A field study was then performed to further test those landraces that successfully emerged (≥ 75%) from the 25 cm depth in the growth chamber. Results indicate that some of the evaluated Native American landraces have a greater capacity to emerge from depth than BSSS-53. Emergence capacity was not related to initial seed weight. Mesocotyl elongation largely accounted for successful emergence from greater planting depths. The landraces partitioned relatively more dry matter to roots than shoots compared to BSSS-53. These results suggest that several of these Native American landraces may be useful for the development of maize varieties more tolerant to deep planting.

Keywords

Native American Maize Landraces, Emergence from Depth, Mesocotyl Length, Radicle

*Deceased

1. Introduction

Native farming systems in the Southwestern U.S. are examples of agronomic systems that have persisted under adverse conditions. Studying these agricultural and social systems, including genetic resources, may provide information that will contribute to the development of a sustainable agronomic future. Within species genetic diversity is important for the "future evolution" of that species; maintaining diversity also allows breeders to have more genetic stock to work with in the future [1]. The characterization of plant genetic resources is needed to document potential traits available for crop improvement and to increase the genetic diversity of crops [2].

Early growing season conditions in the Corn Belt often include wet soils and freezing temperatures, which can prevent timely planting or significantly delay germination and emergence. Planting date has a strong influence on yield; late planting dates generally result in reduced grain weight [3]. Optimally, maize would be planted early in the season and not emerge until after the frost-free date, which is around May 10th in Iowa.

To help alleviate these issues, the corn industry is working on developing polymer seed coatings designed to suppress seed germination until soil temperatures are favorable for seedling development [4]. A supplemental or alternative strategy to seed coatings, which may be particularly useful for organic producers, would be to develop and use varieties adapted to deeper planting. Deeper planting may delay the emergence of the growing point, extending protection of the sensitive growing point from spring frost damage. Temperature extremes do not kill the plant if the growing point is protected [5]; thus if maize is planted deeper, the planting time window may be expanded.

Maize native to the U.S. Southwest is renowned for its capacity to emerge from extraordinary depths ranging from 8 to 45 cm (**Table 1**). The genetics responsible for emergence from these depths could be useful in modern improved maize lines. Native Americans of the Southwest traditionally plant their open-pollinated maize landraces deeply in order to place seed into moist soil to attain germination and stand establishment in a dry climate [6]. Deep planting also anchors plants against flood and wind, and reduces seedling loss to bird predation [7].

In the first half of the 20th century, some research was conducted in the U.S. on the importance of planting depth and emergence in maize [8] [9] [10]. Because of the depth that the Native Americans traditionally planted their maize, studies were performed on the emergence capacity of some Southwest landraces. For example, Navajo maize was more successful at emerging from depth when compared with a Chinese maize line and a Boone County (Corn Belt) maize line [9]. In a similar study, a variety of Navajo maize was compared to a Corn Belt variety; the Navajo maize was also superior to the U.S.13 double cross hybrid maize for emergence from depth [10]. More recently, Troyer (1997) identified genes responsible for long mesocotyl length from Hopi-Kokoma maize plants.

The previous studies that evaluated emergence from deep planting each

Table 1. Landraces and BSSS-53 evaluated for emergence capacity and seedling characteristics. Landrace names indicate tribal affiliation and/or place of original acquisition.

Variety	Identifier	Seed Stock Source	Endosperm Type	Traditional Planting Depth	Trials[B]
Havasupai	PI 317675	NCRPIS[A]	floury	10 to 40-cm	C1, C3
Havasupai-Hopi	PI 476870	NCRPIS[A]	floury	10 to 40-cm	C1
Hopi	PI 213735	NCRPIS[A]	floury	15 to 45 cm	C1, C3
Hopi, Hotevilla	PI 213734	NCRPIS[A]	floury	15 to 45 cm	C1
Hopi, Kokoma	PI 213733	NCRPIS[A]	floury	15 to 45 cm	C1, C2, C3, F1, F2
Hopi, New Oraibi	PI 476869	NCRPIS[A]	flint/floury	15 to 45 cm	C1, C3
Hopi, Shungopovi	PI 420250	NCRPIS[A]	flint/floury	15 to 45 cm	C1, C2, C3, F1, F2
Mojave	PI 218186	NCRPIS[A]	floury	10 to 15 cm	C1
Navajo, Kayenta	PI 311229	NCRPIS[A]	flint/floury	15 to 45 cm	C1
Tohono O'odham	Z01-007 Z01-011	Native Seeds/ SEARCH, Tucson, AZ	floury	10 to 15 cm	C1
Zuni		Muenchrath, ISU	flint/floury	8 to 30-cm	C1, C2, C3, F1, F2
BSSS-53		A. Hallauer, ISU	dent	< 6-cm	C1, C2, C3, F1, F2

[A]NCRPIS = North Central Regional Plant Introduction Station in Ames, Iowa. [B]C1 = Chamber trial 1, C2 = Chamber trial 2, C3 = Chamber trial 3, F1 = Field trial 1, F2 = Field trial 2.

involved one or two of the Southwest landraces; the present study tests 11 landraces for emergence capacity from various planting depths. Hypothesis 1: Landraces of maize native to the U.S. Southwest consistently emerge from greater planting depths than BSSS-53.

The mesocotyl allows emergence of Southwest landraces from their traditional planting depths of 8 to 45 cm [9] [11]. Consistent with traditional planting depths, Hopi maize has mesocotyls up to 36-cm long [11]; Navajo maize has been shown to have mesocotyls of 30-cm [9]. Mesocotyl lengths of Corn Belt maize, customarily planted up to 6-cm deep, only reached a 10-cm length. In studies on planting depth and emergence, mesocotyl length was not limited by seed reserves [9] [11]. Hypothesis 2: We further hypothesize that the mesocotyl lengths of the 11 landraces of southwestern US maize will be longer than BSSS-53.

2. Materials and Methods

2.1. Genetic Materials

Eleven maize landraces, native to Arizona and New Mexico and associated with Native American groups who customarily plant maize deeply, were evaluated for their capacity to emerge from various depths and their seedling characteristics were documented (Table 1). The landraces have floury and/or flinty endosperms. Six landraces, collected on the Hopi Reservation, were included specifically because of their renowned capacity to emerge from extraordinary depths, 10 - 45 cm [9] [12] [13]. The other five landraces are usually sown at 8 - 45 cm [6] [14] [15] [16] [17]. Corn Belt inbred dent line, Iowa Stiff Stalk Synthetic, BSSS-53 (S7 generation), served as a comparison to estimate the relative emergence capacity of the landraces; many of today's elite commercial hybrids were derived, in part, from BSSS populations [18].

Seed was increased from seed stocks obtained from A. Hallauer (Agronomy Department, Iowa State University), the USDA-ARS North Central Regional Plant Introduction Station, Ames IA, the Native Seeds/SEARCH, Tucson AZ, or collected 9 May 1997 on the Zuni Reservation by Muenchrath (**Table 1**). To maintain the genetic diversity within each variety and generate experimental materials, more than 200 plants of each variety were grown at Ames, IA in 2001 by the authors. At least 100 ears of each variety were pollinated using a chain-sib mating system to prevent self-pollination and reciprocal crossing, which is ideally used to maintain the diverse genetics of a plant population [19]. Chain-sib mating is a system that uses pollen from one plant to pollinate the next plant in line, which is repeated until the end of the line where pollen from the final plant is brought back to the first plant in line for pollination.

2.2. Seed Characteristics

Germination percentage and 100-kernel weight were determined in late fall of 2001 for each variety to evaluate general seed quality [20]. To compare seed of similar physical size, seed of each variety was screened through a series of sieves, 11/64 to 26/64. Only those seeds in the 20/64 to 24/64 sieve class were included in the study. Seed industry standard accepts seed sizes between 16/64 and 26/64 screens [21].

2.3. Treatments

Emergence capacity was evaluated in a sequence of three controlled-environment tests in 2001-2002 (Chamber trials 1, 2, and 3), and in two field tests in 2002-2003 (Field trials 1 and 2; **Table 1**). The objectives of Chamber trials 1 and 2 were to (a) screen landraces for capacity to emerge from depth, and (b) examine seedling characteristics relative to emergence success. Based on the results of the Chamber trial 1, Chamber trial 3 focused on emergence capacity of a subset of landraces.

The two field trials were conducted to evaluate emergence under different field conditions.

- Chamber trial 1 screened eleven landraces and BSSS-53 for emergence capacity from 5, 15, and 25 cm planting depths.
- Chamber trial 2 further screened the three landraces that consistently emerged (≥ 75% emergence success) from 25 cm in Chamber trial 1, plus BSSS-53, for their capacities to emerge from 5, 35, and 45 cm depths.

Seedling characteristics and radicle, mesocotyl, and shoot lengths (see **Figure 1**) were documented in Chamber trials 1 and 2 to examine relationships among characteristics and emergence success.

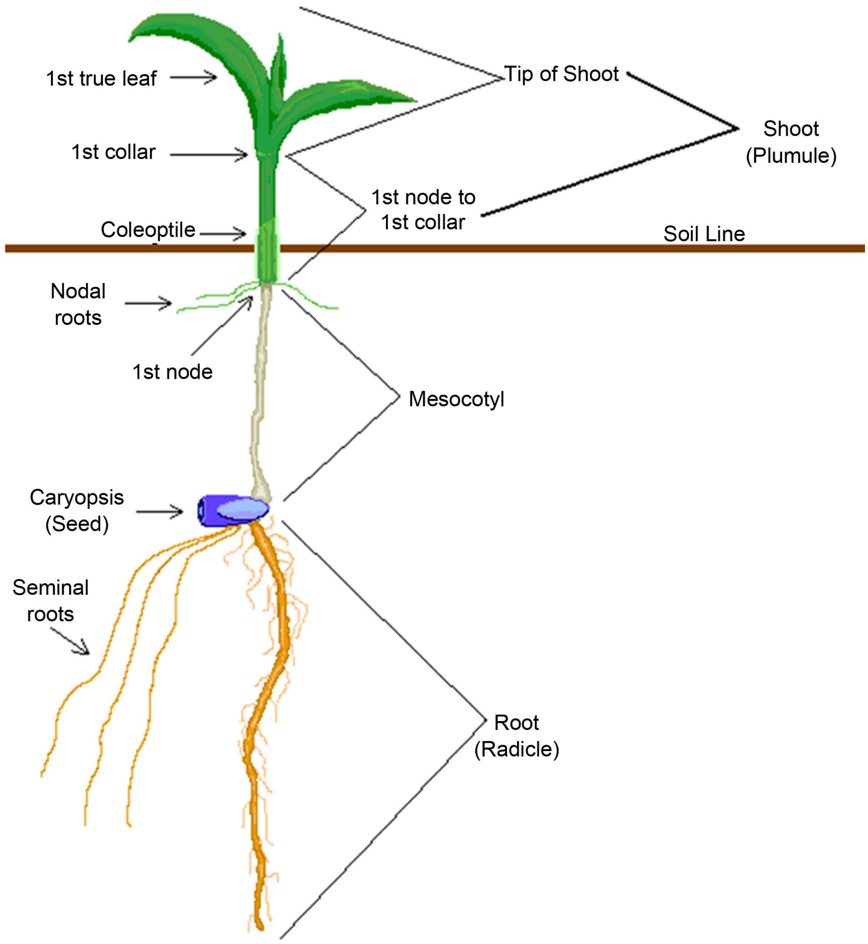

Figure 1. Diagram of maize seedling parts.

- Chamber trial 3 tested BSSS-53 and seven landraces, based on their performance in Chamber trial 1; only those landraces that exhibited > 50% emergence success from 25 cm were advanced to this study. Limiting the number of landraces included in Chamber trial 3 facilitated sampling more individuals per variety at the 25 cm depth.
- Field trial 1 tested those varieties included in Chamber trial 2 for emergence from 5, 15, and 25 cm under summer field conditions, when temperature and moisture conditions were favorable for emergence.
- Field trial 2 repeated Field trial 1 the following spring, when conditions were cooler and wetter.

2.4. Controlled Environment Trials

One 2.74 m × 1.22 m growth chamber (Conviron Model CMP 3244 Growth Chamber, Winnipeg, Manitoba Canada) was used for all controlled environment studies. Temperatures were similar among all trials averaging 25.1˚C (SE 0.001), 25.0˚C (SE 0.003), and 25.4˚C (SE 0.003) for trials 1, 2, and 3, respectively. Relative humidity varied somewhat among trials. Relative humidity averaged 60%

(SE 0.12), 77% (SE 0.13), and 62.4% (SE 0.19) in Chamber trials 1, 2, and 3, respectively. Lights (fluorescent Sylvania F72T12 cool-white light [75%] and incandescent Sylvania 100-W lamps [25%]) provided 12-h of 125 μE/m2s light per 24-h period in all of the controlled environment studies.

In Chamber trials 1, 2, and 3, each seed was planted at its target depth in a 60-cm × 10.2-cm polyvinylchloride (PVC) pipe planting apparatus containing sterile, coarse quartz sand. Sand was obtained from Unimin Co. (LeSueur, MN, USA) and particle-size analysis determined by the Iowa State University Pedometrics Lab using the pipette method (USDA-NRCS-NSSC, 1996). The sand medium was 9% medium, 85% coarse, and 6% very coarse sand per the particle-size analysis.

Each planting apparatus was cut longitudinally to facilitate seedling retrieval at the end of each trial. Two hose clamps fastened matched pipe halves together, with one clamp 20-cm from the top of the pipe and the other at 2-cm from the pipe base. The lower clamp also secured commercial grade Weed-X® porous landscape fabric (Dalen Products Inc., Knoxville, TN, USA) on the bottom of the pipe; the landscape cloth allowed drainage while retaining the sand medium. Moist, autoclaved sand was placed in the bottom of each planting apparatus up to the desired planting depth. One seed was centered on the sand surface and the remaining pipe volume filled with moist sand to 2-cm from the upper edge of the pipe.

Pipes were placed in random order and spaced approximately equidistantly in the growth chamber. The bank of lights was situated 1 m above the top of the PVC pipes. A HOBO® H8 Pro relative humidity and temperature data logger (Onset Computer Co., Bourne, MA, USA) was placed in center of the growth chamber, approximately level with the tops of the pipes, to monitor conditions. Each pipe was watered with 250 ml distilled water every 48 h. Each pipe was covered with aluminum foil to reduce moisture loss and minimize seedling exposure to light until emergence. At seedling emergence, a hole was made in the foil just large enough to allow the seedling access to light.

2.5. Field Trials

Field trials 1 and 2 were conducted at the Iowa State University Bruner Research Farm, located approximately 10 km southwest of Ames, IA. Field trial 1 was planted 2 Aug 2002 following oats in Clarion loam soil (Fine-loamy, mixed, mesic Typic Hapludolls) with a bulk density of 1.24 g/cc. Field trial 2 was planted 22 May 2003 after soybean in Canisteo silty clay loam soil [Fine-loamy, mixed (calcareous), mesic Typic Haplaquolls] with a bulk density of 1.30 g/cc. Plots were tilled with one pass of a field cultivator prior to planting. In each of these trials, seed were sown 25 cm apart within the row, with 76-cm between rows. A hand-held jab planter (Almaco, Nevada, IA) was used to plant at the 5 cm depth. A narrow-blade spade was used to slot-plant seed at the 15 and 25 cm depths.

Emergence was monitored for 29 or 30-d after planting and checked periodically through the end of the growing seasons. In Field trials 1 and 2, no additional seedlings emerged later than 15 and 20-d after planting, respectively. Failed seedlings were not examined.

An automated weather station, located about 100 m from the field plots, recorded air temperature, rain, and soil temperature and volumetric moisture content (VMC) at 10-cm depth. During Field trial 1 from 2 Aug to 30 Aug 2002, air temperature ranged between 8.0˚C and 33.3˚C, and averaged 22.1˚C. Soil temperature and soil moisture ranged between 17.8˚C and 20.5˚C, and between 34% and 40% VMC, respectively. Mean soil temperature and soil moisture at 20-cm depth were 19.3˚C and 39% VMC. Total precipitation was 170.27-mm, about 45% greater than Iowa's normal August rainfall [22].

During Field trial 2 from 22 May to 21 June 2003, precipitation totaled 16.51-mm. Air temperature ranged between 7.1˚C and 32.4˚C, and averaged 17.8˚C. Mean soil temperature and moisture at 20-cm depth were 11.2˚C and 36% VMC, respectively. Soil temperature and moisture ranged between 10.0˚C and 12.1˚C, and between 33% and 39% VMC.

Mean soil temperature was 5.9˚C and 14.0˚C cooler during Field trials 1 and 2, respectively, than the 25.2˚C mean temperature of the growth chamber studies. Emergence occurs in 5 to 6-d from the usual planting depth of about 5 cm in moist soil at an average soil temperature of about 21˚C; emergence is delayed 1-d for each 2.6-cm increase in planting depth due to cooler soil temperatures and greater distance to the surface [23]. Under controlled conditions, shoot and radicle elongation rates are greatest at soil temperatures of 30˚C [24].

2.6. Data Collection

In Chamber trials 1 and 2, initial seed weight of each kernel was determined before planting. Emergence and developmental stages [24] [25] were monitored every 24-h, beginning 2-d after planting and continuing for the 14-d duration of each replication in Chamber trials 1, 2, and 3. Emergence was monitored every 1 to 2-d in Field trials 1 and 2, beginning 4-d after planting and continuing for one month; thereafter, plots were occasionally checked for emergence of additional seedlings.

Seedling characteristics were examined in Chamber trials 1 and 2. To retrieve intact seedlings at the end of each trial, PVC pipes were disassembled and the sand gently removed from around seedlings. The distance of the exposed seedling's kernel from the base of the pipe was measured to account for any settling after planting. Each extracted seedling was rinsed in water to remove remaining sand. Radicle, mesocotyl, and shoot (to first leaf collar) lengths were measured (**Figure 1**). Each seedling was partitioned into seed remainder, radicle-plus-seminal-roots, and shoot; shoot included all tissues above the seed. Partitioned seedlings were dried for 48-h at 70˚C and weighed to determine dry matter. Seed utilization was calculated with the formula: [(initial seed weight–seed weight remaining at harvest)/initial seed weight] × 100.

2.7. Experimental Design and Statistical Analysis

Experiments were randomized complete block designs, with one or two variables and multiple replications (Table 2). Variety or variety-x-planting depth combinations were randomly assigned to location within each replication.

To maintain consistent chamber conditions, one replication was initiated and another ended each week, resulting in a one-week overlap of replications. During the first and final replications, the other half of the chamber was filled with 36 'filler' pipes prepared in a similar manner as in the trial replication; no data were collected from the filler pipes. In Chamber trial 3, each replication consisted of 80 pipes, filling the entire chamber.

Descriptive statistics and correlations were calculated in Excel™ (Microsoft Corp. Redmond, WA). Analyses of variance were performed using the General Linear Model (GLM) procedure of SAS, version 8.1 (SAS Institute, 1999). Means were separated using Tukey's LSD at $P \leq 0.05$ level. There were no significant interactions in the controlled environment studies, and therefore, only the main effects are reported. Data are reported as mean and standard error (SE).

3. Results

3.1. Seed Characteristics

Landrace 100-kernel weights were consistent with those reported by the Germplasm Resources Information Network, GRIN [26]. The mean 100-kernel weight of the landraces, 0.24 g (SE 0.01), was lower than that of BSSS-53, which was 0.32 g. All varieties had the greatest proportion of their seed in the 20/64 to 24/64-inch sieve class; specific proportions were not quantified.

In germination tests to assess general seed quality, all varieties exhibited at least 96% germination, as defined by radicle protrusion. Excluding abnormal seedlings, per the AOSA (2000) criteria for germination, mean germination percentage of landraces was 88.1% (SE 0.17) and BSSS-53 was 93%.

3.2. Emergence Capacity

Controlled Environment Trials: With the exception of one Mojave seed in Chamber trial 1, all seed germinated (radicle protrusion) in the three controlled environment studies. Retrieved seedlings that had failed to emerge commonly

Table 2. Experimental design details for each of the five trials by variale, combination, replication and planting dept treatments.

Trials	Experimental Design			
	Number of Variables	Combinations	Replications	Planting Depths
Chamber Trail 1	2 (variety and depth)	36	12	5, 15, 25 cm
Chamber Trial 2	2 (variety and depth)	12	4	5, 35, 45 cm
Chamber Trial 3	1 (variety)	-	4	25 cm
Field Trial 1	2 (variety and depth)	12	3	5, 15, 25 cm
Field Trial 2	2 (variety and depth)	12	3	5, 15, 25 cm

displayed rotted shoots, embryonic leaves prematurely grown through the coleoptilar tip, or shoots doubled over well below the surface. These observations suggest that extending the duration of each replication beyond the 14-d period of these trials would not have improved emergence success.

In Chamber trial 1, emergence from the 5 cm depth was 100% for all varieties, and 80% to 100% from 15 cm (data not shown). Although emergence percentage from 25 cm did not significantly differ among varieties, the trend was that the landraces emerged more frequently than BSSS-53. From 25 cm depth, the landraces exhibited a mean emergence of 59.9% (SE 4.1) and BSSS-53 exhibited 41.7% (SE 0.32).

In Chamber trial 2, BSSS-53 and each of the four landraces tested exhibited 100% emergence from the control depth, 5 cm. No BSSS-53 seedlings emerged from 35 or 45 cm planting depths. Mean emergence of landraces from the 35 cm depth was 14% (SE 0.24) with no significant differences among landraces. None of the landraces emerged from 45 cm during the 14-d period of the trial.

Since the restricted sample size may have masked variety differences in emergence capacity in Chamber trial 1, Chamber trial 3 tested a larger sample of those landraces that exhibited > 50% emergence success from 25 cm in the Chamber trial 1 screening, plus BSSS-53. In Chamber trial 3, the mean number of emerged landrace seedlings was 53% (SE 0.11), which differed significantly ($P < 0.0001$) from the 10% success of BSSS-53 (SE 0.13). Additionally, each landrace individually was significantly more successful at emerging from 25 cm depth than BSSS-53 (**Table 3**).

Field Trials: Two field trials were performed to evaluate emergence capabilities of the varieties under different field conditions. To avoid confounding emergence capacity with effects of wet and cool conditions that often accompany spring planting, Field trial 1 was conducted in August when soil temperatures and moisture were conducive to rapid germination and emergence. Optimum ambient temperature for maize germination is 20˚C - 22˚C [27]. Field trial 2

Table 3. Results of Chamber trial 3 emergence success (%) from 25cm depth of the seven landraces and BSSS-53. Different lowercase letters indicate significant differences among varieties at 0.05 probability level by Tukey's LSD test.

Variety	Traditional Planting Depth	Success at 25 cm Mean (SE)
Havasupai	10 - 40 - cm	45% ab
Hopi	15 - 45 cm	40% b
Hopi, Kokoma	15 - 45 cm	55% ab
Hopi, New Oraibi	15 - 45 cm	43% b
Hopi, Shungopovi	15 - 45 cm	68% ab
Majave	10 - 15 cm	50% ab
Zuni	8 - 30-cm	73% a
Landrace Mean		53% (0.11)
BSSS-53	< 6-cm	10% c

tested emergence under spring conditions, which are ordinarily cool compared to August temperatures. Spring planting in 2003 was delayed to 22 May, because wet conditions prevented field operations.

Similar to the results of the controlled-environment studies, emergence success in Field trials 1 and 2 generally decreased with increasing planting depth. Under both Field trial 1 and 2 conditions, emergence success differed ($P<0.0001$ and 0.0129, respectively) among varieties across planting depths (Table 4). More specifically, from the 25 cm depth there were significant differences between varieties. As in Chamber trial 3, Zuni maize exhibited the greatest emergence capacity from 25 cm in the field studies. The other landraces did not emerge significantly better from 25 cm than did BSSS-53 under field conditions. Under the spring conditions of Field trial 2, BSSS-53's emergence did not differ from that of the Zuni germplasm at 5 or 15 cm, but did at 25 cm.

3.3. Seedling Characteristics

Seedling characteristics were determined on seedlings retrieved in Chamber trials 1 and 2 to investigate the relationships between characteristics and emergence success.

Morphology: For Chamber trial 1, mesocotyl length differed across planting depths ($P < 0.0001$), increasing with increased planting depth (Table 5), and was strongly correlated with planting depth ($r = 0.81$). At each depth, BSSS-53 had the shortest mean mesocotyl length (Table 5) and the average length of landrace mesocotyls was longer than BSSS-53's ($P = 0.0005$).

As expected, total shoot length tended to increase with increasing planting depth. Mesocotyl length accounted for a greater proportion of total shoot length

Table 4. Results of Field Trial 1 and 2 emergence success (%) of the three landraces and BSSS-53. Different lowercase letters indicate significant differences among varieties at 0.05 probability level by Tukey's LSD test.

Variety	Field 1 Aug 2002		
	5 cm Mean (SE)	15 cm Mean (SE)	25 cm Mean (SE)
Hopi, New Oraibi	97.7%	70.0%	30.0% b
Mojave	97.7%	90.0%	20.0% b
Zuni	97.7%	66.7%	66.7% a
Landrace Mean	97.7% (0.01)	75.6% (0.03)	38.9% (0.03)
BSSS-53	100%	90.0%	20.0% b
Field 2 May 2003			
Hopi, New Oraibi	90.0%	50.0% ab	36.7% ab
Mojave	96.7%	46.7% b	10.0% b
Zuni	93.3%	73.3% ab	53.3% a
Landrace Mean	93.3% (0.76)	56.7% (1.79)	33.3% (0.96)
BSSS-53	93.3%	80.0% a	20.0% b

Table 5. Mean mesocotyl length (cm) of each variety at each planting depth for Chamber 1. Different lowercase letters indicate significant differences among varieties at 0.05 probability level by Tukey's LSD test.

Variety	5 cm Mean (SE)	15 cm Mean (SE)	25 cm Mean (SE)
Havasupai	5.17 (0.25) ab	12.21 (0.67) ab	14.79 (1.61) a
Havasupai-Hopi	4.83 (0.19) ab	13.17 (0.55) ab	15.55 (1.46) a
Hopi	5.00 (0.17) ab	13.42 (0.55) ab	17.32 (1.14) a
Hopi, Hotevilla	4.92 (0.22) ab	13.59 (0.47) ab	18.85 (1.25) a
Hopi, Kokoma	5.63 (0.20) a	13.45 (0.50) ab	17.08 (1.45) a
Hopi, New Oraibi	5.13 (0.31) ab	13.36 (0.83) a	18.59 (1.64) a
Hopi, Shungopovi	5.13 (0.28) ab	12.58 (0.96) ab	15.96 (1.61) a
Mojave	4.83 (0.22) ab	12.18 (0.54) ab	15.41 (1.32) a
Navajo, Kayenta	5.25 (0.24) ab	12.50 (0.64) ab	17.77 (1.34) a
Tohono O'odham	4.83 (0.17) ab	11.27 (0.88) ab	12.75 (1.56) a
Zuni	5.13 (0.29) ab	13.54 (0.40) a	18.54 (1.24) a
Landrace Mean	5.08 (0.23)	12.85 (0.62)	16.61 (1.42)
BSSS-53	4.50 (0.17) b	10.55 (0.61) b	12.67 (1.10) a

with increasing planting depth. Mesocotyl length for the landraces averaged 48% (SE 0.01) of total shoot length when planted at 5 cm, 67% (SE 0.01) at 15 cm, and 75% (SE 0.02) at 25 cm; BSSS-53 averaged 48% (SE 0.02) when planted at 5 cm, 60% (SE 0.07) at 15 cm, and 75% (SE 0.06) at 25 cm. Therefore, at the greater planting depths, shoot length above the mesocotyl apparently contributes less towards emergence than at the shallower depths.

Those landraces that most consistently emerged from 25 cm in Chamber trial 1 (Hopi New Oraibi, Mojave and Zuni) rarely opened shoots prematurely. If they did fail, they more commonly rotted before reaching the surface.

For Chamber trial 1, mean landrace radicle length [at 5 cm depth = 46.6-cm (SE 1.0), at 15 cm = 38.7-cm (SE 0.89) and at 25 cm = 30.1-cm (SE 0.72)] differed ($P < 0.0001$) across all planting depths from BSSS-53 radicle length [at 5 cm = 36.6-cm (SE 2.02), at 15 cm = 28.8-cm (SE 2.06) and at 25 cm = 25.8-cm (SE 2.07)]. Also, regardless of variety, radicle length decreased as planting depth increased.

Dry Matter: In Chamber trial 1, initial seed weight was not correlated with emergence success ($r = -0.20$), and seed utilization did not differ significantly among planting depths across varieties. Regardless of depth, seed utilization remained relatively constant within each variety (data not shown).

Average root-to-shoot dry matter ratios of the landraces [mean 1.26 (SE 0.08)] over all depths in Chamber trial 1, were different ($P = 0.0017$) from BSSS-53 (mean 0.67).

However, root-to-shoot ratios did not explain emergence capacity. The ratios did not correlate with emergence success at 25 cm ($r = -0.23$).

4. Discussion

4.1. Seed Characteristics

This difference between 100-kernel weights of landraces and BSSS-53 may be due, in part, to differences in their endosperm types. BSSS-53 is a dent type, whereas the landraces are floury and flint types [26]. Endosperms of dent maize are denser than floury and flint types, and therefore, dent seed tends to be 10 to 12% heavier than floury and flint seed [28].

4.2. Emergence Capacity

Controlled Environment Trials: Based on the results from the larger sample size of Chamber trial 3, emergence capacity trends among the landraces were not entirely consistent with the customary planting depths associated with each landrace in its native environment. However, the Zuni landrace, which is usually planted at 8 - 30-cm depth, exhibited the most consistent emergence capacity from the 25 cm depth, 73% (SE 0.27). Also, the Mojave landrace with a traditional planting depth of 10 - 20-cm emerged 50% (SE 0.41) of the time from the 25 cm depth.

Hopi traditionally plant maize at greater depths, 10 - 45 cm (see **Table 1**), but success from the 25 cm planting depth only ranged from 40% - 68% with no statistical differences between varieties of the Hopi landraces. Similarly, the Havasupai landrace with a traditional planting depth of 10 - 40-cm emerged 45% (SE 0.20) of the time from the 25 cm depth (**Table 3**).

4.3. Seedling Characteristics

Morphology: Mesocotyl growth slows or ceases when the coleoptile is exposed to light [29]. Although foil over the tops of the containers excluded light, elongated mesocotyls of numerous seedlings, regardless of variety, apparently ceased growth before reaching the soil surface, and their shoots prematurely grew out of the coleoptiles. The prematurely opened shoots of some of the seedlings doubled over as they continued growth through the sand; few of these seedlings successfully emerged from 15 or 25 cm depth. In his study of emergence capacity from depth, [9] noted that most seedlings that underwent shoot expansion more than 2-cm from the soil surface failed to emerge.

Competition between radicle and mesocotyl for seed storage compounds to support growth may have limited radicle length. Alternatively, the smaller soil volume below the seed at the greater planting depths may have restricted radicle length. Seedlings extracted from the 25 cm planting depth exhibited radicles that were more curled and thickened at the point of contact with the landscape cloth at the base of the container than those planted at shallower depths.

Dry Matter: Based on the results of this study, seed weight is not an indicator of potential emergence capacity. Reference [10] found that the average Navajo kernel was 20% smaller than the average U.S. 13 kernel, but had better emergence capacity; the Navajo variety efficiently utilized seed reserves while U.S. 13

seedlings consistently failed to emerge and still had dry weight remaining in the seed.

In a study on inbred maize seedling root morphology, lines with fewer seminal roots had greater total root dry matter [30], which support the results of the present study where the landraces had fewer seminal roots than BSSS-53.

The greater relative allocation of dry matter to roots among landraces may contribute to adaptation to their native arid and semiarid environments. Varieties of drought tolerant sorghum (*Sorghum bicolor* L. Moench) exhibit greater root-to-shoot ratios than do drought-susceptible varieties [31].

5. Conclusions

The study tested the hypothesis that eleven landraces of maize native to the U.S. Southwest have a greater capacity to emerge from deeper planting depths than a representative of Corn Belt varieties. BSSS-53, adapted to the Corn Belt, is ordinarily planted up to 6-cm deep, whereas the landraces are native to agricultural systems that typically plant at depths ranging from 10 - 45 cm. Variation in emergence capacity existed within and among landraces, and customary planting depths of a landrace were not a reliable indicator of consistent emergence capacity under the conditions tested. Among the landraces tested, Zuni maize consistently exhibited the greatest capacity to emerge from extraordinary depths under both controlled environment and field conditions. Of those landraces that did emerge when deeply planted, mesocotyl length largely explained emergence success.

Additional research is needed to better understand landrace characteristics and mechanisms identified in this study; specifically, investigations of root architecture and tolerance of drought and frost. Given the relatively precarious and harsh conditions of the native environments of these landraces, it is likely that these landraces possess genes for tolerance to such conditions as limited and unreliable moisture availability, temperature extremes, and nutrient limitations. Drought-prone areas may be interested in using these genetic characteristics to improve crop capacity to access valuable moisture reserves. Also, further characterization of these landraces could identify other beneficial traits that could be useful in breeding efforts or to increase the genetic diversity of maize.

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