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# Quantifying the expression of potato genetic diversity in the high Andes through growth analysis and modeling

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ABSTRACT

Crop growth analysis and modeling based on a slightly modified version of the LINTUL model was used for the assessment of the effect of genetic diversity, as expressed by differences in characteristics such as ploidy, parentage and other specific traits, on the growth and yield responses of Andean potatoes to agroecological conditions in Bolivia. The aim of the present study was to conduct a comparative growth analysis of nine genotypes to describe their performance under the prevalent conditions in the high Andes. We also simulated the performance of nine genotypes from the species *Solanum tuberosum* subspecies *andigenum* and *tuberosum*, *Solanum ajanhuiri*, and their hybrids as affected by frost. The simulations were run using a user-friendly simulation model based on the LINTUL framework.

Three native genotypes: Ajanhuiri (*S. ajanhuiri*), Gendarme and Waycha (*S. tuberosum* ssp. *andigenum*); one introduced genotype: Alpha (*S. tuberosum* ssp. *tuberosum*); and five hybrids (Condori, Tunari, Sajama, Illimani, and Totoreña) provided the crop data required as inputs to the model, from field experiments conducted over four years under favorable management conditions. Each experimental location also provided daily weather data required by the model. Genotypic differences, ascribed to parentage and ploidy, were evidenced by differences in growth response observed under a range of simulated frost scenarios. The diploid *ajanhuiri* showed better canopy cover and yield than most tetraploids. However, the average yield of the tetraploids was reduced by including the long day Alpha genotype (*tuberosum*), which did not perform as well as the others. Nevertheless, Alpha showed higher harvest index than the average of the short day genotypes and hybrids. *Andigenum* genotypes showed 12% higher yields than the *andigenum* hybrids. Gendarme showed the best growth parameters overall followed by Waycha. The adapted LINTUL model was validated as it adequately ($R^2 > 0.88$) reproduced observed field responses in the calibration experiments. This correspondence between the simulations and the experimental results demonstrated the adequacy of the model, which explained more than 82% of the variations in growth parameters. All statistical metrics used to test the validity of the model to simulate potato yield and yield components in the high Andes showed the model's robustness.



## 1. Introduction

Potato is an important food crop (Walker et al., 1999; Hijmans, 2001) that originated in the Andes (Hawkes, 1990; Spooner et al., 2005). Potato breeding programs in the region have aimed at the generation of new genotypes with higher yield, improved tolerance to biotic and abiotic stresses, and good quality characteristics (Estrada, 1999; Gabriel et al., 1999, 2001). However, the adoption of varieties from breeding programs has been variable between regions, and sometimes between production zones within a region (Wiegers et al., 1999) and potato production in many areas of the Andes is based on native species and varieties that are often grown in mixtures (Terrazas et al., 1998, 2007; Terrazas and Valdivia, 1998).

Genetic diversity in cultivated potato is large and includes diploids ($2n = 2x = 24$), triploids ($2n = 3x = 36$), tetraploids ($2n = 4x = 48$) and pentaploids ($2n = 5x = 60$). Seven species, including *Solanum tuberosum* subspecies *tuberosum* (tetraploid), *S.*

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**Table 1**
General description of the locations where the experiments were conducted.

| Location | Latitude S | Longitude W | Altitude (masl) | Year | Rainfall (mm) | Minimum temperature (°C) | Maximum temperature (°C) | PAR (MJ m$^{-2}$) | Texture |
|---|---|---|---|---|---|---|---|---|---|
| Belen | 16°01′ | 68°44′ | 3640 | 1997 | 710 [350] | 3.6 | 17.2 | 9.9 | CL |
| Koari | 17°26′ | 65°35′ | 3500 | 1997 | 535 [535] | 4.9 | 22 | 11.2 | CL |
| Patacamaya 1 | 17°14′ | 67°57′ | 3780 | 1997 | 350 [340] | 4.1 | 19.9 | 10.4 | SiCL |
| Patacamaya 2 | 17°14′ | 67°55′ | 3789 | 1998 | 350 [350 + 87[a]] | 4.6 | 18.7 | 10.4 | SaCL |
| Patacamaya 3 | 17°16′ | 67°55′ | 3789 | 1998 | 350 [350] | 4.6 | 18.7 | 10.4 | SaCL |
| Puchuni | 17°16′ | 68°13′ | 3950 | 1998 | 713 [513] | 2.4 | 17.4 | 10.3 | SiL |
| Laurani | 17°14′ | 68°11′ | 3850 | 1999 | 480 [430] | 3.3 | 16.8 | 10.3 | CL |
| Toralapa | 17°31′ | 65°40′ | 3430 | 1993 | 535 [442] | 4.4 | 18.4 | 9.6 | CL |

Where C is clay, L is loam, Sa is sand and Si is silt. '[ ]' Rainfall is during the crop cycle.
[a] Irrigation.

*tuberosum* ssp. *andigenum* (tetraploid), *Solanum juzepckzukii* (triploid), and *Solanum ajanhuiri* (diploid) have been described (Hawkes, 1990; Ochoa, 1990; Estrada, 1999).

At lower and intermediate altitudes of the Andes the genotypes of the species *S. tuberosum* ssp. *andigenum* and *S. tuberosum* ssp. *tuberosum* are the most widely cultivated whereas the other species predominate at altitudes higher than 3500 m above sea level. The *Solanum juzepczukii* stands out for its high drought and frost tolerance (Tourneux et al., 2003), but its tubers are bitter due to a high solanine content requiring processing for direct human consumption (Rea, 1992; Arbizu and Tapia, 1994). The genotypes of the *S. ajanhuiri* species have similar tolerance but do not have high solanine contents.

Biotic and abiotic threats are frequent and widespread throughout the Andes. Andean farmers respond mainly by planting combinations of several species and varieties into their fields. The constraints facing these farmers demand going beyond the analysis of yield differences in cultivar trials conducted under non-limiting conditions (Hijmans, 2003; Hijmans et al., 2003). A more clear definition of yield differences under the most frequent natural growth limiting factors is needed to: (1) generate information to support breeding programs in the selection of improved genetic material to cope with present and future climatic conditions; and (2) arrive at more robust recommendations to improve the productivity of farmers' complex cropping systems.

The problem of accounting for yield variation in terms of growth and development of the crop is complex, for it involves the effect of external factors on all the physiological processes of the plant, the interrelation between different processes, and their dependence on the genetic constitution of the plant. All these interrelations are difficult to measure under field conditions. To assess the differences in yield a method such as growth analysis has been widely used (Watson, 1952). Comparative growth analysis and its translation into potato growth models constitute a useful tool, particularly under climate variability and global climate change conditions.

The growth rate of a crop well supplied with water and nutrients and free from pests and diseases is closely proportional to the light absorbed and to net assimilation rate (Spitters, 1988). Total accumulated biomass is obtained by integrating this assimilation rate over time. Tuber yield, in turn, is determined by the net rate of assimilation, the fraction of net assimilates partitioned to tubers, and the duration of tuber growth (Ingram and McCloud, 1984).

With the development of more complete growth models other plant characteristics have been taken into account. For example maximum canopy cover (MCC), light interception variables such as the rate of relative increase of light interception (Ro), initial fraction of light interception at plant emergence (Fo) and the time when the fraction of light intercepted is reduced to 50% ($t_{0.5}$) are used in models developed at Wageningen. Also, instead of net assimilation rate models calculate light interception and use RUE (radiation use efficiency; also called LUE light use efficiency) to calculate dry matter growth.

Potato growth analyses so far reported are mostly limited to the temperate *S. tuberosum* ssp. *tuberosum* genotypes. Reports of this type of analysis for Andean species and hybrids are virtually inexistent in the literature.

The aim of the present study was to conduct a comparative growth analysis of nine genotypes to describe their performance under the prevalent conditions in the high Andes. We also wanted to simulate the performance of a set of new genotypes, as affected by extreme scenarios involving frost. This set was a choice of nine genotypes from the species *S. tuberosum* subspecies *andigenum* and *tuberosum*, *S. ajanhuiri*, and their hybrids. The simulations were run using a user-friendly simulation model based on the LINTUL framework.

**Table 2**
Characteristics of potato genotypes included in the analysis based on ploidy and progenitors.

| Genotype | Ploidy | Presence of progenitors[a] in percentage | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | and | tub | ajh | stn | cur | phu | tor | acl | dms |
| Ajanhuiri | 2*n* | | | 100 | | | | | | |
| Gendarme | 4*n* | 100 | | | | | | | | |
| Waycha | 4*n* | 100 | | | | | | | | |
| Alpha | 4*n* | | 100 | | | | | | | |
| Condori[b] | 4*n* | 44 | 16 | 12.5 | 12.5 | 12.5 | | | | 12.5 |
| Tunari[b] | 4*n* | 62.5 | 25 | | | | | 12.5 | | |
| Sajama[b] | 4*n* | 25 | 50 | | | | 12.5 | | 12.5 | |
| Illimani[b] | 4*n* | 50 | | | | | 25 | 25 | | |
| Totorena[b] | 4*n* | 50 | | | | | 25 | 25 | | |

[a] Cultivated species: and, *andigenum*; tub, *tuberosum*; ajh, *ajanhuiri*; stn, *stenotonum*; cur, *curtilobum*; phu, *phureja*. Wild species: tor, *toralapanum*; acl, *acaule*; dms, *demissum* (Ochoa, 1990).
[b] New hybrids generated.