General, specific combining ability, and heritability in potato genotypes *(Solanum tuberosum* L.*)* for agronomic traits

Aptitud combinatoria general, específica y heredabilidad en genotipos de papa (*Solanum tuberosum* L.) para características agronómicas

Capacidade geral, específica de combinação e herdabilidade em genótipos de batata (*Solanum tuberosum* L.) para características agronômicas

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Abstract

Potato (*Solanum tuberosum* L.) is a key crop in Peru due to its nutritional value and its potential for agronomic genetic improvement, which justifies further research in the selection of promising parents and crosses. This study aimed to estimate general combining ability (GCA), specific combining ability (SCA), and heritability for key agronomic traits: plant height, earliness, and the number and weight of tubers per plant, under the climatic conditions of Huancayo, Peru. Sixteen F_1 families derived from a full diallel cross (Griffing's model I, method I, fixed effects) among four parents (Mariva, Redondo, Redondo Achatado, and Oblongo) were evaluated. The trial was conducted using a randomized complete block design with three replications. The analysis included ANOVA, estimates of GCA, SCA, and reciprocal effects. Highly significant differences ($p < 0.01$) were detected among the combinations. Mariva showed the highest GCA for plant height (5.266), while the Redondo Achatado × Redondo cross exhibited the highest SCA (6.404); for earliness, the GCA of Redondo Achatado (0.056) and the SCA of Redondo Achatado × Mariva (0.952) were outstanding; regarding tuber number per plant, Redondo had the highest GCA (3.258) and the Redondo × Redondo Achatado cross the highest SCA (8.982); for tuber weight, Redondo had the best GCA (0.107) and Oblongo × Redondo the highest SCA (0.449). Heritability ranged from 0.419 to 0.596, indicating moderate to high genetic variation. The high values of GCA and SCA, along with the observed heritability, confirm the potential of these parents to improve potato yield.

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Resumen

La papa (*Solanum tuberosum* L.) es clave en el Perú por su valor alimentario y su potencial de mejoramiento genético agronómico, lo cual justifica profundizar en la selección de progenitores y cruzas promisorias. Este estudio tuvo como objetivo estimar la aptitud combinatoria general (ACG), específica (ACE) y la heredabilidad para características agronómicas clave: altura de planta, precocidad, número y peso de tubérculos por planta, bajo condiciones climáticas de Huancayo, Perú. Se evaluaron dieciséis familias F_1 obtenidas mediante un cruzamiento dialélico completo (método I, modelo I de Griffing, efectos fijos) entre cuatro progenitores (Mariva, Redondo, Redondo Achatado y Oblongo). El experimento se condujo en un diseño de bloques completos al azar con tres repeticiones. El análisis incluyó ANDEVA, estimaciones de ACG, ACE y efectos recíprocos. Se detectaron diferencias altamente significativas ($p < 0,01$) entre combinaciones. Mariva mostró la mayor ACG en altura de planta (5,266) y la cruza Redondo Achatado × Redondo la máxima ACE (6,404); en precocidad destacaron la ACG de Redondo Achatado (0,056) y la ACE de Redondo Achatado × Mariva (0,952); en número de tubérculos por planta sobresalieron la ACG de Redondo (3,258) y la ACE de Redondo × Redondo Achatado (8,982); para peso de tubérculos resaltaron la ACG de Redondo (0,107) y la ACE de Oblongo × Redondo (0,449). La heredabilidad osciló entre 0,419 y 0,596, indicando variación genética de magnitud intermedia-alta. Los valores elevados de ACG y ACE, junto con la heredabilidad observada, confirman el potencial de estos progenitores para mejorar el rendimiento de la papa.

Palabras clave: ACG, ACE, cruzas dialélicas, heredabilidad, rendimiento, varianza genética.

Resumo

A batata (*Solanum tuberosum* L.) é um cultivo fundamental no Peru devido ao seu valor alimentar e ao seu potencial para o melhoramento genético agronômico, o que justifica aprofundar a seleção de genitores e cruzamentos promissores. Este estudo teve como objetivo estimar a capacidade geral de combinação (CGC), capacidade específica de combinação (CEC) e a herdabilidade para características agronômicas-chave: altura da planta, precocidade, número e peso de tubérculos por planta, sob as condições climáticas de Huancayo, Peru. Foram avaliadas dezesseis famílias F_1 obtidas por meio de um cruzamento dialélico completo (Método I, Modelo I de Griffing, efeitos fixos) entre quatro genitores (Mariva, Redondo, Redondo Achatado e Oblongo). O experimento foi conduzido em delineamento de blocos ao acaso com três repetições. A análise incluiu ANOVA, estimativas de CGC, CEC e efeitos recíprocos. Detectaram-se diferenças altamente significativas ($p < 0,01$) entre as combinações. Mariva apresentou a maior CGC para altura da planta (5,266) e o cruzamento Redondo Achatado × Redondo obteve a maior CEC (6,404); para precocidade, destacaram-se a CGC de Redondo Achatado (0,056) e a CEC de Redondo Achatado × Mariva (0,952); para número de tubérculos por planta, a CGC de Redondo (3,258) e a CEC de Redondo × Redondo Achatado (8,982) foram superiores; para peso de tubérculos, sobressaíram a CGC de Redondo (0,107) e a CEC de Oblongo × Redondo (0,449). A herdabilidade variou entre 0,419 e 0,596, indicando variação genética de magnitude intermediária a alta. Os altos valores de CGC e CEC, juntamente com a herdabilidade observada, confirmam o potencial desses genitores para o aumento do rendimento da batata.

Palavras-chave: CGC, CEC, cruzamentos dialélicos, herdabilidade, rendimento, variância genética.

Introduction

Potato (*Solanum tuberosum* L.) is a strategic crop in Peru, both for its nutritional value and for its economic relevance. Peru, the Andean region, is one of the main centers of origin and diversification of this species; it is home to a great genetic wealth of native and improved cultivars (Ovchinnikova *et al.,* 2011). In 2023, Peru recorded a production of more than 5.1 million tons, despite having faced rainfall deficiency that year (MIDAGRI, 2024), positioning itself as the largest potato producer in Latin America. However, its average yield per hectare is still low regarding its genetic potential, due to factors such as limited genetic variability in cultivated materials, susceptibility to biotic and abiotic stresses, and poor adaptation to changing conditions (MIDAGRI, 2018, 2024). In this context, genetic improvement is a priority tool to increase crop productivity, adaptability, and quality, which justifies the need to identify superior parents and promising crosses through genetic analyses such as general combining ability (GCA), specific combining ability (SCA), and heritability.

The diallel design, proposed by Griffing (1956), allows the simultaneous estimation of general combining ability (GCA) and specific combining ability (SCA), providing essential information on the additive and non-additive effects that control agronomic traits of interest. GCA is mainly associated with the additive action of genes, which makes it useful for the recurrent selection of superior parents (Saavedra *et al*., 2021), while SCA reflects the specific interaction between parental combinations, making it possible to identify hybrids with unexpected superior behavior due to dominance effects or epistasis (Mugisa *et al*., 2022).

Several studies in potatoes and other crops indicate that, for yield-related traits such as the number and weight of tubers per plant, the non-additive effects may exceed additive effects in magnitude (Amiri *et al*., 2020; Mugisa *et al*., 2022), especially in heterogeneous environments. However, the heritability of the trait directly influences the effectiveness of selection: when it is high, prioritizing GCA is recommended, whereas under conditions of moderate or low heritability, SCA can offer advantages for direct cloning (Onofri *et al.,* 2021; Russell & Sandall, 2005).

In the case of potato, a tetraploid and allogamous species, the genetic complexity is high, which justifies the use of models that consider fixed genetic components. Griffing's model I, method I, is appropriate for this type of analysis, as it also allows for the estimation of reciprocal effects and components of genetic variance useful for calculating narrow-sense heritability (Pooni *et al*., 1984; Mohammed *et al*., 2016).

Despite advances in breeding programs, information on specific hybrid combinations with agronomic potential under high Andean conditions remains limited. Therefore, the present study aimed to estimate GCA, SCA, reciprocal effects, and heritability in four potato genotypes for agronomic traits such as plant height, earliness, and number and weight of tubers per plant to identify promising parents and crosses for inclusion in genetic improvement programs.

Materials and methods

The research was carried out during the 2023-2024 agricultural season in two phases: the generation of F_1 hybrids in greenhouses and the field evaluation of the resulting progeny. The controlled crosses were performed in the greenhouse of the Agricultural Sciences Research Center (CICA) of Huancayo, while the field phase was carried out in the district of Quichuay, province of Huancayo,

department of Junín, Peru. The experimental field is located at 3.606 m.a.s.l., with a clay-loam soil texture (pH 7.1) and an Andean climate characterized by temperatures ranging between 4 and 18 °C.

The genetic material was made up of four potato genotypes: Redondo, Redondo Achatado, Oblongo (*Solanum tuberosum* L.), and Mariva (*Solanum tuberosum* subsp. *andigenum*). These parents, provided by CICA, were established from seed tubers. Male parents were established in pots to induce flowering and collect pollen, while female parents were managed using the brick method (figure 1). This method consisted of making cuts in the stolons during the flowering phase to prolong it, facilitate manual pollination, and improve the production of botanical seeds.

Figure 1. Planting tubers using the brick method.

Once the parent plants entered flowering, controlled crosses were made by hand pollination. Prior to pollination, manual emasculation of the bud flowers of the female parents was performed, extracting their stamens before dehiscence to prevent self-fertilization. Immediately after, fresh pollen collected from the male parents was applied to the stigmas of the emasculated flowers. Each pollinated flower was labeled with the identification of the cross (female parent × male parent), and the fruit (berry) was allowed to develop on the mother plant. Approximately 6-8 weeks after pollination, when the berries reached maturity (darkening of the epidermis), they were harvested manually. From the harvested berries, the sexual seeds corresponding to each cross were extracted (table 1), which were washed and dried at room temperature for temporary storage.

Table 1. Codes of hybrid potato clones.

Treatment N°	Parental genotype used	Crossbreeding of origin	Clonal code
1	Mariva	Mariva × Vacapa Ccallum	IPC 720025
2	Redondo	Yungay × Mariva	GOP-031513.02
3	Redondo Achatado	Yungay × Mariva	GOP-031513.01
4	Oblongo	Yungay × Perricholi	GOP-031512.09

IPC: International Potato Center, "720025" corresponds to the access code of the IPC genebank/material; Clonal code (example: GOP-031513.02): GOP = plant breeder initials, 03 = breeding code, 15 = year of crossbreeding, 1 = female parent, 3 = male parent, and 02 = breeding number within the progeny.

The botanical seeds from each cross were sown in seedbeds (trays lined with paper towels). Once germinated, the seedlings were transplanted into vessels with substrate and kept in a nursery until they reached around 10 cm in height (with 2-3 true leaves). Next, the seedlings were transplanted in the final field of Quichuay, in rows 0.90 m apart, with a distance of 0.30 m between plants (figure 2). Immediately after transplanting, establishment irrigation was carried out, and bottom fertilizers were applied to ensure a good start of the crop.

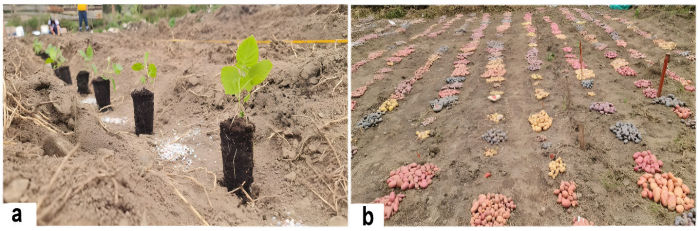

Figure 2. a: Transplanting of seedlings to the final field. b: Harvesting of hybrid potato tubers in the second cultivation phase.

The field experiment was conducted under a randomized complete block design (RCBD) with 16 families and three replications. All possible combinations of the complete diallel cross among the four parents were evaluated (method I, Griffing's model I with fixed genetic effects): 4 self-fertilizations, 6 direct crosses, and 6 reciprocal crosses (Griffing, 1956). Each treatment (hybrid family and self-fertilized parent) was established in one plot per block, with 15 plants per plot (45 plants per family in total). A total of 720 plants were transplanted in an experimental area of 216 m². During the crop cycle, standard cultural practices for potatoes were carried out, including hilling, manual weed control on two occasions, and preventive applications against insects and pathogens.

Variables evaluated

Three important agronomic variables were measured: plant height at 120 days after transplanting, number of tubers per plant, and total tuber weight per plant in kilograms. These measurements were averaged at the plot and treatment level.

Statistical analysis

The collected data were initially subjected to an analysis of variance (ANDEVA) under the randomized complete block design model. Subsequently, the diallel analysis was carried out according to Griffing's model I, method I (1956), considering parents, direct and reciprocal crosses. This analysis allowed for the estimation of general combining ability (GCA), specific combining ability (SCA), and reciprocal effects.

The general statistical model applied was:

$$Y_{(ijk)} = \mu + g_i + s_{ij} + m_i + l_{ij} + B_k + e_{ijk}$$

Where: $Y_{(ijk)}$ is the observed value; μ, the overall mean; g_i, the effect of GCA of parent i; s_{ij}, the effect of SCA between parents i and j; e, the maternal effect; l_{ij}, the reciprocal effect; B_k, the block effect; and e_{ijk}, the random error.

Estimated effects:

$ACG_i = \bar{Y}_{i.} - \mu$

$ACE_{ij} = \bar{Y}_{ij} - \mu - ACG_i - ACG_j$

Variances and narrow-sense heritability (h^2):

Additive variance:

Dominance variance:

Total phenotypic variance:

Heritability (h^2):

All statistical analyses were carried out using the InfoGen version 2018 software (Balzarini & Di Rienzo, 2003) and Microsoft Excel 2019 for organization and preliminary data processing.

Results and discussion

Diallel analysis allowed the decomposition of observed variance into additive genetic effects (GCA), non-additive effects (SCA), and reciprocal effects (table 2). Highly significant effects ($p<0.01$) of GCA and SCA were detected in the evaluated variables, indicating the joint participation of additive and non-additive gene action in the expression of these traits. Significant reciprocal effects ($p<0.05$) were also observed in plant height, number, and weight of tubers per plant, suggesting the influence of maternal or cytoplasmic effects on these variables.

Table 2. Analysis of variance (ANAVA) of Griffing's method for tubers in potato (*Solanum tuberosum* L.) genotypes and hybrids.

Source of variation	Gl	Plant height (CM)	Earliness (CM)	Number of tubers (CM)	Weight of tubers (CM)
GCA	3	141.094**	0.042ns	76.592**	0.083*
SCA	6	27791.964**	0.677**	20919.638**	0.33**
Reciprocal	6	44.764**	0.045ns	73.443**	0.056*
Error	30	12.191	0.024	15.712	0.022

Plant height

In plant height (table 3), Mariva stood out with a high general combining ability (GCA) of 5.266, indicating a strong ability to transmit genes related to vegetative vigor, in accordance with previous studies in potatoes carried out by Khan *et al*. (2013). Likewise, the crosses Redondo × Redondo Achatado (6.404), Redondo × Oblongo (4.870), and Mariva × Redondo Achatado (3.128) showed significant values of specific combining ability (SCA), indicating favorable non-additive interactions for this trait. As indicated by Luthra *et al*. (2005), additive effects are essential for vegetative traits, but specific combinations may provide additional advantages.

Table 3. General and specific combining ability effects for plant height evaluated at harvest (120 days after planting).

Parents	Mariva (1)	Redondo (2)	Redondo Achatado (3)	Oblongo (4)
Mariva (1)	5.266*	-5.593	4.205	-4.276
Redondo (2)	-1.396	1.151	3.018	-6.697
Redondo Achatado (3)	3.128	6.404*	-4.487	-3.617
Oblongo (4)	-3.497	4.870	-0.034	-1.930

* = significant at 5 %; ** = significant at 1 %. Values on the main diagonal correspond to the effects of the general combining ability GCA of each parent. Off-diagonal values represent the effects of the specific combining ability SCA of each hybrid combination. Positive values indicate favorable effects on the evaluated variable, and negative values, unfavorable effects.

Number of tubers per plant

For the number of tubers (table 4), the Redondo parent had the highest GCA (3.258), reflecting its ability to transmit prolificacy. In SCA, the combinations Redondo Achatado × Redondo (8.982), Oblongo × Redondo Achatado (7.347), and Mariva × Redondo (7.052) stood out. These results are consistent with Onofri *et al*. (2021), who suggest that combining parents with high GCA and SCA optimizes selection for yield-related traits. This is also consistent with specific findings in potato by Kamara *et. al.* (2021), who recommend dual selection strategies.

Table 4. General and specific combining ability effects for the number of tubers per plant evaluated at harvest (120 days after planting).

Parents	Mariva (1)	Redondo (2)	Redondo Achatado (3)	Oblongo (4)
Mariva (1)	-0.296	-4.151	-6.281	-2.864
Redondo (2)	7.052*	3.258	8.982**	4.560
Redondo Achatado (3)	-1.326	1.679	-4.092	7.347*
Oblongo (4)	-0.967	-0.673	2.160	1.130

* = significant at 5 %; ** = significant at 1 %. Values on the main diagonal correspond to the effects of the general combining ability GCA of each parent. Off-diagonal values represent the effects of the specific combining ability SCA of each hybrid combination. Positive values indicate favorable effects on the evaluated variable, and negative values, unfavorable effects.

Tuber weight per plant

Regarding the weight of tubers per plant (table 5), Redondo showed the best GCA (0.107), highlighting its additive genetic contribution to the development of tuber weight. The hybrid combinations Oblongo × Redondo (0.449), Mariva × Redondo Achatado (0.403), and Mariva × Oblongo (0.101) stood out in SCA, revealing important non-additive effects possibly linked to epistatic or dominant interactions. These findings are in agreement with what was reported by Mohammed *et. al*. (2016), who point out that the yield per plant in potatoes depends significantly on non-additive effects.

Table 5. General and specific combining ability effects for tuber weight per plant evaluated at harvest (120 days after planting).

Parents	Mariva (1)	Redondo (2)	Redondo Achatado (3)	Oblongo (4)
Mariva (1)	-0.059	-0.119	0.217	-0.234
Redondo (2)	0.079	0.107	0.007	-0.226
Redondo Achatado (3)	0.403	0.014	-0.110	0.013
Oblongo (4)	0.101	0.449*	-0.287	0.063

* = significant at 5%; ** = significant at 1%. Values on the main diagonal correspond to the effects of the general combining ability GCA of each parent. Off-diagonal values represent the effects of the specific combining ability SCA of each hybrid combination. Positive values indicate favorable effects on the evaluated variable, and negative values, unfavorable effects.

Tukey's mean test for evaluated agronomic variables

In table 6, the results of Tukey's test ($p < 0.05$) reveal statistically significant differences between the 16 hybrid families evaluated, which shows considerable genetic variability for the agronomic traits studied.

For plant height, the combination Mariva × Mariva (84.31 cm) was statistically superior to the rest of the families, followed by Oblongo × Redondo (82.81 cm), and Redondo × Mariva (82.63 cm). These results suggest a possible favorable additive effect on height transmitted by the parent Mariva, as well as specific combinations with positive non-additive effects, especially when Oblongo is used as a female parent. Darabad *et al*. (2020) point out that a higher plant height could be associated with greater vigor and efficiency in light capture, favoring foliar and photosynthetic development, a desirable condition in high-altitude environments such as Huancayo (3200 m.a.s.l.).

In relation to earliness, it was identified that the crosses Redondo Achatado × Mariva (2.82) and Mariva × Redondo Achatado (2.81) presented a greater number of days until senescence, indicating a longer duration of the vegetative cycle. This behavior could reflect a cumulative additive gene action in favor of delayed maturity, which may be advantageous in areas where the agricultural cycle

is extended. In contrast, Mariva × Mariva, Oblongo × Mariva, and Oblongo × Redondo Achatado showed the lowest values (<1.25), evidencing a genetic pattern oriented towards early maturity. This is consistent with what was reported by Khan *et al*. (2013), who state that additive gene action has a greater influence on the determination of physiological maturity in potatoes.

Regarding the number of tubers per plant, the cross Redondo × Mariva reached the highest average (76.64), followed by Redondo × Redondo Achatado (72.30) and Redondo × Oblongo (70.74). This pattern suggests a positive effect of the Redondo parent when used as a male, reflecting its favorable specific combining ability. According to Onofri *et al*. (2021), the SCA is key to identifying combinations of parents that exceed the expected yield of their individual GCA values, which is observed in these crosses. In addition, the result aligns with the findings of Mugisa *et al*. (2022), who observed in sweet potato that certain hybrid combinations with high SCA values were candidates for direct cloning in vegetative propagation programs.

Finally, for the weight of tubers per plant, the family Oblongo × Redondo showed the highest value (2.42 kg), followed by Mariva × Redondo Achatado (2.03 kg), and Oblongo × Mariva (1.92 kg). These combinations reflect not only favorable specific effects but also the importance of the maternal effect on total yield. As highlighted by Saavedra *et al*. (2021), reciprocal effects may be relevant when the female parent influences the phenotypic expression of complex traits such as yield. Likewise, Mackay *et al*. (2021) state that optimal biomass utilization is explained by the recombination and redistribution of favorable alleles during sexual reproduction. Taken together, these results reinforce the importance of considering both additive (GCA) and non-additive (SCA) and reciprocal effects when selecting parents for potato breeding programs, especially under high-altitude agroecological conditions such as in Huancayo.

Estimation of variance and heritability of height, earliness, and yield per plant evaluated at harvest (120 days after planting)

Table 7 presents the estimates of additive variance, dominant variance, and narrow-sense heritability (h^2) for the traits of plant height, earliness, number and weight of tubers per plant, based on the diallel design proposed by Griffing (1956).

The results show that, in all the traits evaluated, dominance effects predominate, observing that the dominant variance (σ^2D) was consistently higher than the additive variance (σ^2A). This trend evidences the existence of non-additive effects such as dominance and epistasis in the genetic expression of the evaluated traits, coinciding with what was reported by Li *et al.* (2010), who pointed out that many traits in potato yield respond to complex gene interactions. In the case of plant height, a narrow-sense heritability of 0.5951 was obtained, which indicates a moderate to high capacity to transmit this trait to the progeny. This suggests that this trait may respond efficiently to early selection in breeding programs. Regarding earliness, the h^2 value was 0.5718, which also represents a considerable genetic potential, being favorable for selecting early lines adapted to short production cycles or limiting climatic conditions. According to Schmidt *et al*. (2019), this level of heritability allows for effective genetic advancement when combined with adequate environmental control.

For the number of tubers per plant, a heritability of 0.5969 was recorded, which denotes an important genetic influence. This is consistent with what was reported by Maibvisira *et al*. (2018), who found high heritability for yield components, particularly in crosses with well-contrasted parents. In contrast, the weight of tubers per plant had the lowest heritability (0.4190), which indicates that this trait is more influenced by the environment and by non-additive genetic effects. This result suggests that, to improve weight, it is necessary to employ strategies such as the selection of specific hybrid combinations of high SCA, and to perform multifocal evaluations to control the environmental effect. This approach is supported by Mondal et al. (2022), who state that when environmental variance is low compared to genetic variance, genetic control can be more reliably exploited. The estimated values support the use of mixed breeding strategies, combining phenotypic selection based on GCA with the identification of specific crosses with high SCA. This allows for the utilization of both moderate heritability and dominance effects, which are key to developing more productive clonal cultivars better adapted to the agroecological conditions of the Mantaro Valley.

Table 6. Significance test of the means for plant height (cm), earliness, number of tubers per plant, and tuber weight (kg).

O.M.	Families	Plant height (cm)	Earliness	Tubers.plant^{-1}	Weight (kg) tubers.plant^{-1}
1	1×1 (M × M)	84.31 ± 1.56^{a}	1.22 ± 0.08^{d}	57.12 ± 1.33^{abcd}	0.88 ± 0.06^{d}
9	1×2 (M × R)	71.45 ± 1.56^{abcd}	1.83 ± 0.08^{bcd}	68.33 ± 1.33^{abcd}	1.59 ± 0.06^{bcd}
4	1×3 (M × RA)	80.13 ± 1.56^{abc}	2.81 ± 0.08^{a}	50.48 ± 1.33^{d}	2.03 ± 0.06^{ab}
12	1×4 (M × O)	67.58 ± 1.56^{abcd}	1.82 ± 0.08^{bcd}	59.48 ± 1.33^{abcd}	1.45 ± 0.06^{bcd}
3	2×1 (R × M)	82.63 ± 1.56^{ab}	1.51 ± 0.08^{cd}	76.64 ± 1.33^{a}	1.83 ± 0.06^{abc}
14	2×2 (R × R)	64.44 ± 1.56^{bcd}	1.51 ± 0.08^{cd}	60.93 ± 1.33^{abcd}	1.25 ± 0.06^{bcd}
5	2×3 (R × RA)	78.11 ± 1.56^{abc}	1.67 ± 0.08^{bcd}	72.30 ± 1.33^{ab}	1.60 ± 0.06^{bcd}
10	2×4 (R × O)	69.41 ± 1.56^{abcd}	2.14 ± 0.08^{abc}	70.74 ± 1.33^{abc}	1.97 ± 0.06^{abc}
8	3×1 (RA × M)	71.72 ± 1.56^{abcd}	2.82 ± 0.08^{a}	63.04 ± 1.33^{abcd}	1.60 ± 0.06^{bcd}
7	3×2 (RA × R)	72.07 ± 1.56^{abc}	1.84 ± 0.08^{bcd}	54.33 ± 1.33^{bcd}	1.58 ± 0.06^{bcd}
16	3×3 (RA × RA)	53.55 ± 1.56^{d}	1.60 ± 0.08^{bcd}	51.77 ± 1.33^{cd}	1.23 ± 0.06^{cd}
15	3×4 (RA × O)	61.95 ± 1.56^{cd}	1.11 ± 0.08^{d}	69.02 ± 1.33^{abcd}	1.26 ± 0.06^{bcd}
6	4×1 (O × m)	76.13 ± 1.56^{abc}	1.22 ± 0.08^{d}	65.20 ± 1.33^{abcd}	1.92 ± 0.06^{abc}
2	4×2 (O × R)	82.81 ± 1.56^{ab}	2.35 ± 0.08^{ab}	70.74 ± 1.33^{abc}	2.42 ± 0.06^{a}
11	4×3 (O × RA)	69.19 ± 1.56^{abcd}	1.22 ± 0.08^{d}	54.32 ± 1.33^{bcd}	1.23 ± 0.06^{cd}
13	4×4 (O × O)	66.82 ± 1.56^{abcd}	1.75 ± 0.08^{bcd}	64.21 ± 1.33^{abcd}	1.44 ± 0.06^{bcd}

Different letters in each column indicate significant differences according to Tukey's test ($p < 0.05$). Redondo (R), Redondo Achatado (RA), Oblongo (O), Mariva (M).

Table 7. Analysis of genetic components and heritability of height, earliness, and yield.

Trait	Additive Variance (σ^2A)	Dominant variance (σ^2D)	Heritability (h^2)
Plant height	6378.49100	17095.24500	0.59510
Earliness	0.14600	0.40200	0.57180
N° of tubers/plant	4808.76300	12863.95500	0.59690
Tuber/plant weight	0.05600	0.18900	0.41900

Conclusions

The genetic combinations Redondo × Redondo Achatado, Oblongo × Redondo, and Redondo × Oblongo showed highly significant SCA effects that increased plant height, earliness, number, and weight of tubers per plant.

Narrow-sense heritability was moderate to high for height (0.595), number of tubers (0.597), and earliness (0.572), confirming an additive component that can be exploited by selecting parents with high GCA.

In tuber weight ($h^2 = 0.419$), dominance effects predominated; therefore, it is recommended to exploit heterosis through specific crosses.

Overall, these results support a mixed scheme: selecting Redondo and Oblongo as base parents and establishing the hybrids Redondo × Redondo Achatado and Oblongo × Redondo as commercial clones, with the aim of increasing potato yields in the Mantaro Valley.

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