

RESPONSE OF POTATO VARIETIES TO DIFFERENT SPECIES OF ROOT-KNOT NEMATODE (*Meloidogyne* spp.)

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ABSTRACT

Potato is a fundamental crop for global food security; however, root-knot nematodes threaten its production. The aim of this study was to identify *Meloidogyne* species and assess the response of different potato varieties to this pathogen. Nematode populations were analyzed through biochemical characterization using esterase isoenzymes, identifying four species: *M. incognita* (Esterase I1, I2), *M. arenaria* (Est. A1, A2), *M. hapla* (Est. H1, H2), and *M. ethiopica* (Est. E3). Subsequently, thirteen potato cultivars were evaluated under greenhouse conditions, in pots, and inoculated with 5,000 eggs and J2 juveniles of nematodes. After 55 days, the number of galls, eggs, and the reproduction factor (RF) were measured. The *Yungay* cultivar exhibited the highest susceptibility, as evidenced by the high number of galls (25.68), eggs (74,633), and a high reproduction factor (RF) of 19.24. In contrast, the *Ccompis*, *Venturana*, and *Ruki* cultivars showed lower susceptibility, with the following results: galls (3.51, 3.56, and 1.00), eggs (1,783, 4,083, and 0), and RF (0.360, 0.472, and 0), respectively. Additionally, resistance was evaluated using three key indices: galls index (GI %), reproduction index (RI %), and RF. In this regard, the *Yungay* variety showed high susceptibility (IN=100 %, IR=100 %, RF=13.46), in contrast to resistant cultivars like *Ruki* (GI=5.5 %, RI=0 %, RF=0.00) and *Andina* (GI=15.3 %, RI=2.6 %, RF=0.35), which inhibited nematode penetration (GI %) and reproduction (RI %). This study provides key information on the resistance and susceptibility of potato cultivars to nematodes, which is useful for guiding management strategies and selecting appropriate varieties in areas with a high presence of root-knot nematodes.

Additional keywords: Inoculation, *Meloidogyne*, selection, susceptibility, resistance

RESUMEN

Respuesta de variedades de papa a diferentes especies del nematodo agallador (*Meloidogyne* spp.)

La papa constituye un cultivo fundamental para la seguridad alimentaria global; sin embargo, los nematodos agalladores comprometen su producción. Se identificaron las especies de *Meloidogyne* y se evaluó la respuesta de distintas variedades de papa frente a este patógeno. Se analizaron poblaciones de nematodos mediante caracterización bioquímica con isoenzimas estererasas, identificándose four especies: *M. incognita* (Esterase I1, I2), *M. arenaria* (Est. A1, A2), *M. hapla* (Est. H1, H2), and *M. ethiopica* (Est. E3). Posteriormente, se evaluaron trece cultivares de papa bajo condiciones de invernadero en macetas, luego inoculadas con 5.000 huevos y juveniles J2 de nematodos. Tras 55 días, se midieron el número de agallas, huevos y el factor de reproducción (FR). El cultivar *yungay* evidenció mayor susceptibilidad por su elevada formación de agallas (25,68), huevos (74.633) y un FR elevado (19,24). En contraste, los cultivares *Ccompis*, *Venturana* y *Ruki* mostraron menor susceptibilidad; agallas (3,51; 3,56 y 1,00), huevos (1.783; 4083 y 0) y FR (0,360; 0,472 y 0) respectivamente. Se evaluó la resistencia, mediante tres índices clave: de Nodulación (IN %), de Reproducción (IR %) y FR; la variedad *yungay* se mostró altamente susceptible (IN=100 %, IR=100 %, FR=13,46) contrastado con cultivares resistentes como *Ruki* (IN=5,5 %, IR=0 %, FR=0,00) y *Andina* (IN=15,3 %, IR=2,6 %, FR=0,35), inhibiendo la penetración (IN %) y la reproducción de nematodos (IR %). Este estudio proporciona información clave sobre la resistencia y susceptibilidad de cultivares de papa frente a nematodos, útil para guiar estrategias de manejo y selección de variedades adecuadas en zonas con alta presencia de nematodos agalladores.

Palabras clave adicionales: Inoculación, *Meloidogyne*, resistencia, selección, susceptibilidad

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INTRODUCTION

Peru is considered the center of origin of the potato, being the country with the greatest

diversity of native potato varieties in the world. The country has over 4,000 identified native potato varieties, with much of the production concentrated in Andean regions such as Cusco,

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Puno, Arequipa, and Ayacucho (Spooner *et al.*, 2005). Potato cultivation in Peru occurs at altitudes ranging from 2,000 to 4,000 meters above sea level, with varieties adapted to these conditions.

Potato production in Peru and other South American countries faces significant challenges, such as infestations by pests and diseases. Late blight (*Phytophthora infestans*), root-knot nematodes, and other fungal and bacterial diseases affect potato crops (Dandurand *et al.*, 2022).

The interaction between potato (*Solanum tuberosum* L.) and nematodes of the genus *Meloidogyne* is a major concern for potato production in several regions worldwide, including countries such as Peru, Colombia, Ecuador, Bolivia, Mexico, the United States, China, India, Kenya, and South Africa, where these pathogens pose a serious threat to crop production and yield. Root-knot nematodes are phytopathogenic parasites that affect plant roots, causing the formation of galls that impair water and nutrient uptake, resulting in significant productivity losses. These nematodes are responsible for a wide range of damage in potato crops, including yield reduction, tuber quality deterioration, and increased susceptibility to other diseases (Khan *et al.*, 2023; Teklu *et al.*, 2023).

Potato susceptibility to *Meloidogyne* is closely related to the plant's response to nematode infection. The nematode penetrates the plant roots and begins its life cycle, forming galls around the female's body. This damage interferes with the plant's ability to absorb water and nutrients, resulting in a stressed plant with reduced growth and tuber production (Teklu *et al.*, 2023).

In susceptible cultivars, infection can lead to severe infestations that compromise plant physiology. Conversely, some potato varieties exhibit genetic defense responses that can reduce nematode damage. These responses may include partial resistance or tolerance to the nematode, although the plant can still be affected to the extent of reduced yield, but to a lesser degree than highly susceptible plants (Teklu *et al.*, 2023; Potter *et al.*, 2024).

In the Puno region, Flores-Choque *et al.* (2017) highlighted *Meloidogyne* as the most prevalent and damaging genus affecting potatoes. Other authors suggest that improved potato varieties are more susceptible to these nematodes compared to

native varieties (Zapana, 2024).

The objective is to identify *Meloidogyne* species and evaluate the response of potato varieties that are not susceptible to this nematode. This information will help mitigate its effects through integrated pest management (IPM) and the selection and promotion of varieties with greater genetic resistance, which in turn can be utilized by producers, breeding programs, and institutions responsible for sustainable agricultural development.

MATERIALS AND METHODS

Isoenzyme analysis of *Meloidogyne* spp. For biochemical analysis and identification, adult females with a milky white coloration were used. These were placed in capillary tubes with buffer solution (sucrose/Triton X-100) and kept refrigerated (Carneiro and Almeida, 2001). The females were individually transferred to microtubes and then macerated in 15 μ L of a protein extraction solution (20 % sucrose, 2 % Triton X-100, 0.01 % bromophenol blue, and 78 % distilled water). Subsequently, 10 μ L of each protein extract, obtained from the maceration of each female, was applied to the wells of polyacrylamide gels. The standard sample consisted of protein extracts from *Meloidogyne javanica*, which were loaded into at least one well on each prepared gel.

Evaluation of potato varieties response to *Meloidogyne* spp. For the evaluation of the response of potato varieties to *Meloidogyne* populations, thirteen potato varieties (Huayro, Canchan, Peruanita, Silver, Imilla Negra, Yungay, Lomo Blanco, Imilla Blanca, Florcita, Andina, Ccompis, Ventura, and Ruki) were selected for assessment against *Meloidogyne* spp. populations. These varieties were chosen due to their relevance in potato production in the region and their genetic diversity.

Seven plants of each potato variety were grown under controlled conditions. To prevent contamination by other pathogens, sandy loam soil was used and sterilized in an autoclave at 120 °C to eliminate any living organisms present in the soil, ensuring that only the inoculated nematodes were present during the experiment (Ali *et al.*, 2017). Five-liter pots were used to provide adequate space for root development. The plants were

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maintained under greenhouse conditions at temperatures ranging from 20 to 25 °C and relative humidity between 70 and 80 %, conditions that are favorable for both potato growth and nematode reproduction (Lima et al., 2018).

Inoculum preparation of *Meloidogyne* spp. Seven samples of potato roots infested with *Meloidogyne* spp. were collected from different areas of southern Peru. The nematode populations were subsequently multiplied on tomato plants (*Solanum lycopersicum* L.) cv. Rio Grande, which is considered highly susceptible to *Meloidogyne* spp.

The extraction of eggs and second-stage juveniles (J2) of *Meloidogyne* spp. (Coolen and D'Herde, 1972) was performed on roots with galls. The roots were then cut and macerated with 0.5 % NaOCl, and the suspension was filtered through 60, 100, and 400 mesh sieves, followed by centrifugation with kaolin (1,800 rpm, 5 min) and subsequently with 45 % sucrose (1,800 rpm, 1 min). The supernatant was collected, and eggs were counted using a Peters counting chamber under a stereoscopic microscope. The total number of eggs recovered per plant was recorded for the calculation of the Reproduction Factor (RF).

For inoculation, approximately 5,000 eggs and second-stage juveniles (J2) per plant of *Meloidogyne* spp. were used, corresponding to seven populations: two of *M. incognita* (esterase phenotypes I1 and I2), two of *M. arenaria* (esterase phenotypes A1 and A2), two of *M. hapla* (esterase phenotypes H1 and H2), and one of *M. ethiopica* (esterase phenotype E3). Inoculation was carried out by applying 10 mL of nematode suspension (equivalent to 5,000 eggs + J2) around the root zone of potato plants when they had developed the first pair of true leaves, in order to ensure early root infestation during the initial stages of plant development (Sasser, 1980). Subsequently, the plants were maintained under greenhouse conditions until they reached the senescence stage (Lima et al., 2018).

Evaluation of the Response of Potato Varieties. Fifty-five days post-inoculation (dpi), the response of each variety to *Meloidogyne* spp. infestation was evaluated. Plants were carefully removed from the substrate, and roots were washed with running water and visually examined to record the number of galls (NG) formed by the

nematodes (Kim et al., 2017). This assessment allowed classification of the varieties' responses based on the degree of gall formation as an indicator of susceptibility or resistance levels.

In addition to gall assessment, the number of eggs (NH) was quantified for each variety. Significant differences ($p \leq 0.05$) were observed among cultivars, reflecting variability in nematode reproductive capacity. The highest egg counts were recorded in susceptible cultivars, whereas resistant genotypes exhibited significantly lower NH values.

Reproduction factor (RF) and evaluation parameters. The Reproduction Factor (RF) of *Meloidogyne* spp. was calculated as the ratio between the final nematode population (Pf) consisting of eggs and second stage juveniles (J2) recovered from the roots at 55 days post-inoculation (dpi) and the initial nematode population (Pi) inoculated:

$$RF = \frac{Pf}{Pi}$$

Where:

Pf = Total number of eggs + J2 recovered from the roots

Pi = Initial number of inoculated nematodes

RF=1: Indicates no significant reproduction, suggesting resistance or low infestation.

RF>1: Indicates nematode reproduction, suggesting that the cultivar is susceptible.

RF<1: Suggests that the plant has partial or complete resistance to the nematode (Evans et al., 2005).

Evaluation parameters.

-NA (Number of galls): At the end of the experiment, the roots of each plant were harvested and weighed. Subsequently, the number of galls present in each replication was counted.

-NH (Number of eggs): After gall counting, the roots were macerated in a blender with 1 L of water and 5 mL of sodium hypochlorite (NaOCl) to release the eggs. The number of eggs was then quantified using a Peters counting chamber.

-GI (Gall index): Percentage of galling observed in each evaluated cultivar.

-RI (Reproduction index): Ratio between the number of eggs produced (Pf) and the initial number of eggs inoculated (Pi) in each cultivar.

-RG (Reproduction Grade): Represents the nematode's capacity to establish and reproduce

within a host plant, assessed using standardized ordinal scales based on the number of galls or egg masses observed on infected root systems.

Data Analysis and Interpretation. An analysis of variance (ANOVA) was performed to evaluate differences among potato varieties in terms of number of galls (NA), number of eggs (NH), and reproduction factor (RF). When significant differences were detected ($p \leq 0.05$), means were compared using the Scott-Knott clustering test (SK) to identify significant statistically distinct groups among varieties. This procedure allowed classification of the cultivars according to their reaction to *Meloidogyne* spp. as susceptible, resistant, or immune (Seid *et al.*, 2019).

RESULTS AND DISCUSSION

Isoenzyme analysis for *Meloidogyne* spp.

The phenotypes shown in figure 1 represent esterase electrophoresis profiles that allow observation of biochemical differentiation among *Meloidogyne* species. Each species exhibited a specific banding pattern, both in number and relative position, which facilitated their

identification. Specifically, extracts corresponding to *M. incognita* Est. I1 and I2 (RF: 1.05 and 1.10) showed two isoenzyme variants with intense bands in regions of high relative mobility. *M. arenaria* Est. A1 and A2 (RF: 1.20 and 1.29) presented profiles with more dispersed bands in positions characteristic of this species. Meanwhile, *M. hapla* Est. H1 and H2 (RF: 0.95 and 1.18) showed another distinct pattern. Additionally, *M. ethiopica* Est. E3 (RF: 1.25) presented an intense band at an atypical position among species commonly found in potato. This also highlights the intraspecific genetic variability that may influence virulence or adaptation to different potato varieties (Karszen *et al.*, 2013).

These results align with previous studies indicating this technique as reliable for differentiating *Meloidogyne* species (Maleita *et al.*, 2021). However, discrepancies arise when considering the sensitivity and resolution of the method. For example, Medina *et al.* (2017) noted that in diverse populations or hybridization scenarios between species, esterase patterns may become confusing or ambiguous, complicating precise identification using this method alone.

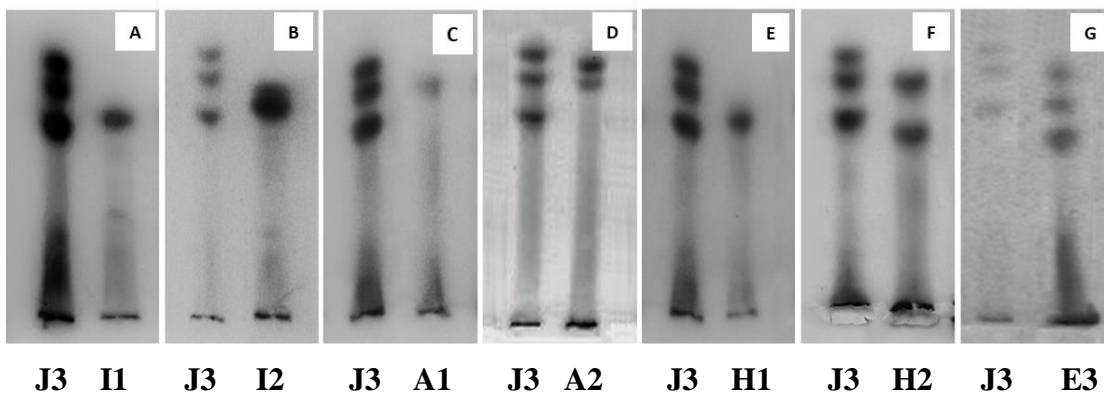


Figure 1. Esterase phenotypes for *Meloidogyne* species. *M. javanica* (Est. J3), used as the standard, followed by *Meloidogyne* species: A and B: *M. incognita* (Est. I1, I2), C and D: *M. arenaria* (Est. A1 and A2), E and F: *M. hapla* (Est. H1 and h2), and G: *M. ethiopica* (Est. E3). Photographs of standard banding patterns obtained by electrophoresis of *Meloidogyne* spp. in roots of potato crops.

Response of potato varieties to different *Meloidogyne* spp. populations. The evaluation of potato varieties comprised the determination of the number of galls (NA), number of eggs (NH), and reproduction factor (RF). Significant differences ($p \leq 0.05$) were detected among

cultivars for all evaluated variables, demonstrating variability in both infection severity and the reproductive potential of the nematode.

According to the analysis, the Yungay variety showed the highest susceptibility at all stages, with high averages of gall production across all

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Meloidogyne spp.: *M. incognita* Est. I1 (25.68 galls) (Table 1), *M. incognita* Est. I2 (24.28) (Table 2), *M. arenaria* Est. A1 (22.61) (Table 3), *M. arenaria* Est. A2 (20.14) (Table 4), *M. hapla* Est. H1 (18.21) (Table 5), *M. hapla* Est H2 (18.33) (Table 6), and E3 (22.21) (Table 7). The number of eggs, especially in I2 (74,633.33 eggs) (Table 2), was significantly elevated. Likewise,

very high RF values were observed, such as 19.24 for E3 (Table 7), indicating massive nematode reproduction. Yungay also exhibited the highest average number of galls across all parameters according to the Scott-Knott classification (“a”) (Tables 1-7), indicating high susceptibility to nematodes.

Table 1. Means of NA, NH, RF, Scott-Knott test $p \leq 0.05$. GI (%), RI (%), RG(1-4) of potato varieties to *Meloidogyne* (I1 - *M. incognita*).

Cultivar	NA	NH	RF	GI (%)	RI (%)	RG (1-4)	Reaction (R)
Yungay	25.68 a	71200	14.24 a	100.0	100.0	4	S
Huayro	8.69 b	8916	1.78 e	33.8	12.5	2	S
Canchan	7.55 c	15416	3.08 c	29.4	21.7	2	S
Peruanita	8.46 b	11933	2.39 d	32.9	16.8	2	S
Silver	5.77 d	24300	4.86 b	22.5	34.1	2	S
Imilla negra	5.67 d	11766	2.35 d	22.1	16.5	2	S
Imilla blanca	3.35 e	6466	1.29 e	13.0	9.1	2	R
Florcita	6.43 d	9083	1.82 e	25.0	12.8	2	S
Lomo blanco	5.65 d	8583	1.72 e	22.0	12.1	2	S
Andina	5.87 d	12416	2.48 d	22.9	17.4	2	S
Ccompis	5.77 d	3133	0.63 f	22.5	4.4	1	R
Venturana	5.165 d	4083	0.82 f	20.1	5.7	1	R
Ruki	1.645 f	1466	0.29 f	6.4	2.1	1	R
CV (%)	8.64	18.94	18.94				
p-value	<0.001	<0.001	<0.001	-	-	-	-

NA: number of galls, NH: number of eggs, RF: reproduction factor (final population/initial population), GI (%): gall index (cultivar nodulations / highest nodulation) $\times 100$, RI (%): reproduction index (cultivar eggs / highest egg count) $\times 100$, R: reaction (Susceptible (RF ≥ 1) and Resistant (RF ≤ 1)) (Oostenbrink, 1966), RG(1-4): reproduction grade (1(R) RF ≤ 1 , 2(MR) $1 < \text{RF} \leq 5$, 3(S) $5 < \text{RF} \leq 10$, and 4(HS) RF > 10). CV: coefficient of variation. Means followed by different letters differ significantly from each other according to the Scott-Knott test ($p \leq 0.05$).

Devindrappa et al. (2025) mention that the number of galls formed on roots is a direct indicator of the severity of *Meloidogyne* spp. infection. Oliveira and Rosa (2021) states that a higher number of galls indicates greater root invasion and consequently more damage to the plant, clearly associating this variety with various genetic, physiological, and morphological factors. Kumar and Singh (2021) indicate that it lacks resistance genes such as Mi-1. Devran et al. (2019) report that roots emit signals favoring egg hatching and the formation of feeding structures for the nematode (Elling, 2013). Other authors corroborate these findings: Oostenbrink (1966) and Wegulo et al. (2009) indicate that

morphologically, its vigorous root system and fragile cell walls facilitate nematode infection and development. Furthermore, it is naturally susceptible, allowing high reproduction of *Meloidogyne*, thus validating the results obtained in this study.

The varieties Huayro and Peruanita also exhibited moderate to high susceptibility; Silver, Imilla Negra, and Florcita showed intermediate values, indicating that they may be tolerant to *Meloidogyne* infections without suffering significant losses. Venturana and Lomo Blanco showed variable responses depending on the *Meloidogyne* spp. The variety Ruki demonstrated greater resistance under all conditions: I2 (2.8)

(Table 2), A2 (1.0) (Table 4), H1 (2.3) (Table 5), H2 (1.0) (Table 6), I1 (1.6) (Table 1), A1 (1.0) (Table 3), and E3 (1.0) (Table 7). Additionally,

data showed zero egg counts in A2, H2, A1, and E3 (Tables 4, 6, and 7, respectively).

Table 2. Means of NA, NH, RF, Scott-Knott test $p \leq 0.05$. GI (%), RI(%), RG(1-4) of potato varieties to *Meloidogyne* species (I2 - *M. incognita*).

Cultivar	NA	NH	RF	GI (%)	RI (%)	RG (1-4)	Reaction (R)
Yungay	24.28 a	74633	14.93 a	100.0	100.0	4	S
Huayro	12.14 b	49366	9.87 b	50	66.1	3	S
Canchan	7.50 c	34650	6.93 c	30.9	55.2	3	S
Peruanita	7.46 c	18100	3.62 d	30.7	46.4	2	R
Silver	6.20 d	41166	8.23 c	25.5	24.2	3	S
Imilla negra	6.03 d	13483	2.70 d	24.8	22.9	2	R
Imilla blanca	4.79 e	7000	1.4 e	19.7	22.8	2	R
Florcita	4.68 e	7866	1.57 e	19.3	18.1	2	R
Lomo blanco	4.54 e	17066	3.41 d	18.7	11.7	2	R
Andina	4.43 e	17000	3.4 d	18.3	10.5	2	R
Ccompis	4.41 e	5416	1.08 e	18.2	9.4	2	R
Venturana	3.56 f	8750	1.75 e	14.7	7.3	2	R
Ruki	2.87 f	3166	0.63 e	11.8	4.2	1	R
CV (%)	10.02	30.79	30.79				
p-value	<0.001	<0.001	<0.001	-	-	-	-

NA: number of galls, NH: number of eggs, RF: reproduction factor (final population / initial population), GI (%): gall index (cultivar nodulations / highest nodulation) $\times 100$, RI (%): reproduction index (cultivar eggs / highest egg count) $\times 100$, R: reaction (Susceptible (RF \geq 1) and Resistant (RF \leq 1)) (Oostenbrink, 1966), RG(1-4): reproduction grade (1(R) RF \leq 1, 2(MR) 1<RF \leq 5, 3(S) 5<RF \leq 10 and 4(HS) RF>10). CV: coefficient of variation. Means followed by the same letter do not differ significantly from each other according to the Scott-Knott test $p \leq 0.05$.

The reproduction factor was 0.0 in A2, H2, A1, and E3 (Tables 4, 6, and 7, respectively), indicating that the nematode did not reproduce. Andina, Imilla Negra/Blanca, and Ccompis also exhibited low infestation levels (galls close to 1, eggs near zero, and reproduction factor \leq 1). Similarly, the varieties Huayro, Peruanita, Silver, Imilla Negra, Florcita, and Venturana showed moderate susceptibility (“b” and “e”) (Tables 1-7). These results partially agree with the studies by Ramos (2020) and Zapana (2024), especially regarding the resistance of some varieties such as Canchan and Huayro. However, slight differences were observed in the exact values of galls and eggs, which may be related to variations in environmental conditions, crop management, or the methodology employed.

It is important to consider that resistance to *Meloidogyne* can be influenced by factors such as crop rotation, soil type, and the use of biofertilizers,

aspects highlighted by Zapana (2024) in her research. Schaffer *et al.* (2017) also identified Ruki as highly resistant (RF<1) to *M. incognita* and *M. javanica* in controlled inoculation studies. Ramatsitsi and Ramachela (2023) reported Ruki with an absence of galls (1 on a scale of 0–5) and zero reproduction of *M. arenaria*, compared to susceptible cultivars like Yungay. These data validate the results obtained in the present study.

The most aggressive *Meloidogyne* spp., were I2 (*M. incognita*) in the Yungay variety, which exhibited the highest reproduction (74,633.333 eggs) (Table 2). Similarly, E3 (*M. ethiopica*) showed the highest reproduction factor (19.24) (Table 7), also in the Yungay cultivar. H1 (*M. hapla*) displayed high variability (CV=67.27 %) (Table 5), indicating that observed values were dispersed across some potato varieties. In other words, the values were neither homogeneous nor consistent.

Lima et al. Response of potato varieties to different species of root-knot nematode**Table 3.** Means of NA, NH, RF, Scott-Knott test $p \leq 0.05$. GI (%), RI (%), RG(1-4) of potato varieties to *Meloidogyne* (A1-*M. arenaria*).

Cultivar	NA	NH	RF	GI (%)	RI (%)	RG (1-4)	Reaction (R)
<i>Yungay</i>	22.61 a	61633	12.33 a	100.0	100.0	4	S
<i>Huayro</i>	4.76 b	49366	9.87 b	21.1	80.1	3	S
<i>Canchan</i>	3.32 d	4066	0.81 f	14.7	6.6	1	R
<i>Peruanita</i>	4.57 b	18100	3.62 c	20.2	29.4	2	S
<i>Silver</i>	4.31 c	6566	1.31 e	19.1	10.7	2	R
<i>Imilla negra</i>	2.73 e	4916	0.98 f	12.1	8.0	1	R
<i>Imilla blanca</i>	3.62 d	7250	1.45 e	16.0	11.8	2	R
<i>Florcita</i>	4.45 b	9650	1.93 d	19.7	15.7	2	S
<i>Lomo blanco</i>	4.10 c	17066	3.41 c	18.1	27.7	2	S
<i>Andina</i>	3.08 e	9116	1.82 d	13.6	14.8	2	S
<i>Ccompis</i>	3.95 c	9433	1.89 d	17.5	15.3	2	S
<i>Venturana</i>	3.71 d	10366	2.07 d	16.4	16.8	2	S
<i>Ruki</i>	1 f	0	0 g	4.4	0.0	1	R
CV (%)	6.81	16.05	16.05				
<i>p</i> -value	<0.001	<0.001	<0.001	-	-	-	-

NA: number of galls, NH: number of eggs, RF: reproduction factor (final population / initial population), GI (%): gall index (cultivar nodulations / highest nodulation) $\times 100$, RI (%): reproduction index (cultivar eggs / highest egg count) $\times 100$, R: reaction (Susceptible (RF \geq 1) and Resistant (RF \leq 1)) (Oostenbrink, 1966), RG(1-4): reproduction grade (1(R) RF \leq 1, 2(MR) 1<RF \leq 5, 3(S) 5<RF \leq 10 and 4(HS) RF>10). CV: coefficient of variation. Means followed by the same letter do not differ significantly from each other according to the Scott-Knott test $p \leq 0.05$.

The number of eggs (NH) exhibited a clear differentiation among potato cultivars, reflecting variations in nematode reproductive success. Highly susceptible cultivars such as *Yungay* consistently showed the highest NH values across all *Meloidogyne* spp., reaching up to 96,200 eggs in E3, indicating optimal conditions for nematode development and reproduction. In contrast, moderately susceptible cultivars, including *Huayro*, *Peruanita*, *Silver*, and *Imilla negra*, presented intermediate NH values, suggesting partial limitation of nematode multiplication. Resistant cultivars such as *Ruki*, *Ccompis*, *Andina*, and *Venturana* exhibited very low or null egg production in several treatments, indicating an effective suppression of nematode reproduction. These results demonstrate that NH is a reliable indicator of host suitability and provides a more accurate assessment of resistance than gall formation alone.

As a primary variable, (NH) reflects the reproductive capacity of the nematode and

provides a direct estimate of its fitness within the host. Unlike gall formation (NA), which only indicates infection establishment, (NH) allows differentiation between cultivars that permit nematode penetration and those that effectively restrict reproduction. Therefore, (NH) constitutes a critical parameter for accurately assessing host resistance.

Consistent with these observations, significant differences among potato cultivars were detected for both gall formation (NA) and egg production (NH) according to the Scott-Knott test ($p < 0.05$). The *Yungay* cultivar exhibited the highest values for both parameters across all evaluations, with gall numbers ranging from 18.21 (H1) (Table 5) to 25.68 (I1) (Table 1), confirming its high susceptibility to *Meloidogyne* infestation. In contrast, *Ruki* showed the lowest values for both gall number (between 1 in A2 and 2.87 in I2) (Tables 4 and 2, respectively) and egg production, indicating a high level of resistance.

Table 4. Means of NA, NH, RF, Scott-Knott test $p \leq 0.05$. GI (%), RI(%), RG(1-4) of potato varieties to *Meloidogyne* spp. (A2 - *M. arenaria*).

Cultivar	NA	NH	RF	GI (%)	RI (%)	RG (1-4)	Reaction (R)
<i>Yungay</i>	20.14 a	64156	12.83 a	100.0	100.0	4	S
<i>Huayro</i>	6.92 c	4366	0.87 b	34.4	6.8	1	R
<i>Canchan</i>	4.48 d	3780	0.75 b	22.2	5.9	1	R
<i>Peruanita</i>	8.14 b	3423	0.68 b	40.4	5.3	1	R
<i>Silver</i>	4.87 d	3446	0.69 b	24.2	5.4	1	R
<i>Imilla negra</i>	1 f	0	0 d	5.0	0.0	1	R
<i>Imilla blanca</i>	1 f	0	0 d	5.0	0.0	1	R
<i>Florcita</i>	2.62 e	826	0.17 d	13.0	1.3	1	R
<i>Lomo blanco</i>	4.33 d	1780	0.356 c	21.5	2.8	1	R
<i>Andina</i>	2.25 e	270	0.054 d	11.2	0.4	1	R
<i>Ccompis</i>	3.51 e	1823	0.364 c	17.4	2.8	1	R
<i>Venturana</i>	5.35 d	2360	0.472 b	26.6	3.7	1	R
<i>Ruki</i>	1 f	0	0 d	5.0	0.0	1	R
CV (%)	18.32	21.42	21.42				
<i>p</i> -value	<0.001	<0.001	<0.001	-	-	-	-

NA: number of galls, NH: number of eggs, RF: reproduction factor (final population / initial population), GI (%): gall index (cultivar nodulations / highest nodulation) $\times 100$, RI (%): reproduction index (cultivar eggs / highest egg count) $\times 100$, R: reaction (Susceptible (RF \geq 1) and Resistant (RF \leq 1)) (Oostenbrink, 1966), RG (1-4): reproduction grade (1(R) RF \leq 1, 2(MR) 1<RF \leq 5, 3(S) 5<RF \leq 10 and 4(HS) RF $>$ 10). CV: coefficient of variation. Means followed by the same letter do not differ significantly from each other according to the Scott-Knott test $p \leq 0.05$.

Other cultivars such as Canchán, Peruanita, and Imilla Blanca presented lower values of both galls and eggs compared to Yungay, suggesting a certain degree of resistance. Similarly, cultivars such as Canchán, Silver, and Imilla negra exhibited reduced gall formation and egg production, indicating a more pronounced limitation of nematode reproduction. In particular, Canchán demonstrated a consistent resistance response, in agreement with findings reported by Zapana (2024), confirming its performance against *Meloidogyne* spp. under different conditions.

These results are consistent with previous studies. Ramos (2020) and Zapana (2024) reported cultivars with reproduction factor (RF) values lower than 1, such as Imilla Negra (RF=0.104), which exhibited resistance to the nematode. Likewise, Alarcón (2017) reported that cultivars such as Canchán and Yungay differ markedly in their resistance due to physiological

and molecular mechanisms, supporting the patterns observed in the present study.

There are statistically significant differences among cultivars ($p \leq 0.0001$), indicating that nematode reproduction is highly influenced by the potato genetic material. The cultivars that showed the lowest values for both gall number and egg production were Ccompis, Venturani, and Ruki. These cultivars exhibited low levels of galling, egg production, and reproduction factor (RF), and were placed in the lowest groups of the Scott-Knott statistical clustering (groups e and f), suggesting a limited capacity of *Meloidogyne* to establish and reproduce on these materials. Furthermore, the low coefficients of variation (CV %) (6.23-18.32 %) observed in Tables 1-7 indicate adequate experimental precision and support the reliability of the obtained results.

However, several studies have reported that the response of potato cultivars to *Meloidogyne* spp. may vary considerably depending on the virulence of the nematode populations and environmental

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conditions. In this context, Zapana (2024) reported high susceptibility in cultivars such as Imilla Blanca and Lomo Blanco, highlighting the

variability in cultivar responses to different nematode populations or growing conditions.

Table 5. Means of NA, NH, RF, Scott-Knott test $p \leq 0.05$. GI (%), RI (%), RG(1-4) of potato varieties to *Meloidogyne* (H1 - *M. Hapla*).

Cultivar	NA	NH	RF	GI (%)	RI (%)	RG (1-4)	Reaction (R)
<i>Yungay</i>	18.21 a	62766	12.55 a	100.0	100.0	4	S
<i>Huayro</i>	9.09 b	7050	1.41 b	49.9	11.2	2	R
<i>Canchan</i>	7.01 c	7666	1.53 b	38.5	12.2	2	R
<i>Peruanita</i>	6.48 c	5266	1.05 b	35.6	8.4	2	R
<i>Silver</i>	7.98 b	6450	1.29 b	43.8	10.3	2	R
<i>Imilla negra</i>	8.42 b	7233	1.44 b	46.2	11.5	2	R
<i>Imilla blanca</i>	7.84 b	4833	0.96 b	43.1	7.7	1	R
<i>Florcita</i>	6.50 c	12000	2.4 b	35.7	19.1	2	R
<i>Lomo blanco</i>	2.56 e	4916	0.98 b	14.1	7.8	1	R
<i>Andina</i>	1 f	0	0 b	5.5	0.0	1	R
<i>Ccompis</i>	4.57 d	1883	0.37 b	25.1	3.0	1	R
<i>Venturana</i>	6.83 c	6383	1.27 b	37.5	10.2	2	R
<i>Ruki</i>	2.38 e	5566	1.11 b	13.1	8.9	2	R
CV (%)	15.93	67.27	67.27				
<i>p</i> -value	<0.001	<0.001	<0.001	-	-	-	-

NA: number of galls, NH: number of eggs, RF: reproduction factor (final population / initial population), GI (%): gall index (cultivar nodulations / highest nodulation) $\times 100$, RI (%): reproduction index (cultivar eggs / highest egg count) $\times 100$, R: reaction (Susceptible (RF \geq 1) and Resistant (RF \leq 1)) (Oostenbrink, 1966), RG(1-4): reproduction grade (1(R) RF \leq 1, 2(MR) 1<RF \leq 5, 3(S) 5<RF \leq 10, and 4(HS) RF>10). CV.: coefficient of variation. Means followed by the same letter do not differ significantly from each other according to the Scott-Knott test $p \leq 0.05$.

In contrast, in the present study the cultivars Ccompis, Venturani, and Ruki showed the lowest values for all evaluated parameters, suggesting reduced susceptibility to the nematode. These cultivars exhibited lower numbers of galls (4.41, 3.56, and 2.87, respectively), eggs (70, 54.17, and 31.67), and a reduced reproduction factor (1.08, 1.75, and 0.63, respectively), indicating a limited capacity of the nematode to multiply on these hosts. Similar findings were reported by Kumar and Singh (2021), who indicated that the reproduction of *Meloidogyne* spp. may vary significantly depending on the host cultivar, reflecting differences in host-parasite compatibility and plant defense mechanisms. Zhang and Gleason (2020) reported that cultivars exhibiting low RF values, such as Yungay and Florcita, may be considered relatively more resistant, since although gall formation may occur in the roots, nematode reproduction is restricted,

thereby reducing its impact on plant growth and development.

The reproduction factor (RF) is a key measure of the nematode's ability to multiply within the host. Yungay recorded significant values, ranging from 12.33 (A1) to 19.24 (E3) (Tables 3 and 7, respectively), confirming its high susceptibility. In contrast, Ruki, Andina, Imilla Blanca, and Ccompis showed values below 1 in several assessments, indicating resistance. Canchán and Peruanita exhibited moderate values, which may suggest partial tolerance.

The Canchán and Peruanita varieties exhibited the highest resistance, consistent with observations by Zapana (2024) and Devran *et al.*, (2019), who highlighted the genetic and physiological traits of certain varieties as defense mechanisms against nematodes. However, the identification of Silver and Imilla Negra as cultivars with moderate to low resistance suggests

that, although these varieties may exhibit some level of resistance, their ability to control

infestation is not as effective as that of more resistant varieties (Potter *et al.*, 2024).

Table 6. Means of NA, NH, RF, Scott-Knott test $p \leq 0.05$. GI (%), RI (%), RG(1-4) of potato varieties to *Meloidogyne* (H2 - *M. hapla*).

Cultivar	NA	NH	RF	GI (%)	RI (%)	RG (1-4)	Reaction (R)
<i>Yungay</i>	18.33 a	67300	13.46 a	100.0	100.0	4	S
<i>Huayro</i>	8.85 b	9050	1.81 b	48.3	13.4	2	R
<i>Canchan</i>	4.14 e	7983	1.60 b	22.6	11.9	2	R
<i>Peruanita</i>	6.42 c	4300	0.86 c	35.0	6.4	1	R
<i>Silver</i>	8.15 b	7933	1.59 b	44.5	11.8	2	R
<i>Imilla negra</i>	7.71 b	9083	1.82 b	42.1	13.5	2	R
<i>Imilla blanca</i>	3.89 e	4716	0.94 c	21.3	7.0	1	R
<i>Florcita</i>	5.36 d	8133	1.63 b	29.2	12.1	2	R
<i>Lomo blanco</i>	3.15 e	3516	0.70 c	17.2	5.2	1	R
<i>Andina</i>	2.81 e	1766	0.35 d	15.3	2.6	1	R
<i>Ccompis</i>	3.53 e	1783	0.36 d	19.3	2.6	1	R
<i>Venturana</i>	7.71 b	4600	0.92 c	42.1	6.8	1	R
<i>Ruki</i>	1 f	0	0 d	5.5	0.0	1	R
CV (%)	17.75	16.66	16.66				
<i>p</i> -value	<0.001	<0.001	<0.001	-	-	-	-

NA: number of galls, NH: number of eggs, RF: reproduction factor (final population / initial population), GI (%): gall index (cultivar nodulations / highest nodulation) $\times 100$, RI (%): reproduction index (cultivar eggs / highest egg count) $\times 100$, R: reaction (Susceptible (RF \geq 1) and Resistant (RF \leq 1)) (Oostenbrink, 1966), RG(1-4): reproduction grade (1(R) RF \leq 1, 2(MR) 1<RF \leq 5, 3(S)5<RF \leq 10, and 4(HS)RF>10). CV: coefficient of variation. Means followed by the same letter do not differ significantly from each other according to the Scott-Knott test $p \leq 0.05$.

A key factor to consider is that the reproduction factor (RF) depends not only on the plant's resistance or susceptibility but also on the initial nematode density, abiotic stress factors such as temperature and humidity, and other elements like fertilization and the crop varieties used (Salazar and Hernandez, 2013; Sikora *et al.*, 2018). Similarly, Hussain *et al.*, (2016) confirm that cultivars with higher reproduction factors (RF) and greater egg counts tend to be more susceptible to the pest. This increased RF may be attributed to a combination of factors, such as greater availability of resources in the roots for the nematode or the plant's inability to effectively defend against nematode attack (Alarcón, 2017).

Similarly, in the subsequent analysis, the Yungay cultivar demonstrated high susceptibility across all evaluated varieties, with reproduction

factors (RF) exceeding 10. Galls index (GI) and reproduction index (RI) values reached 100 % (Tables 1-7), as described by Trudgill (1991). Resistant cultivars interfere with nematode reproduction by limiting female development or egg viability. Ruki, with an RI of 0 %, and Ccompis, with 2.6 %, exhibited near-complete suppression of reproduction, consistent with Bridge *et al.* (2005), who reported that effective resistance maintains RI percentages below 10 %, making these cultivars ideal negative controls for comparative studies. In contrast, Ruki was identified as the most resistant, with RF \leq 0.29 and RI \leq 2.1 % (I1) (Table 1), and absence of eggs in infections by *M. arenaria* and *M. hapla*, indicating strong genetic resistance. These findings align with Medina *et al.* (2017) regarding nematode development suppression in resistant genotypes.

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Cultivar	NA	NH	RF	GI (%)	RI (%)	RG (1-4)	Reaction (R)
<i>Yungay</i>	22.21 a	96200	19.24 a	100.0	100.0	4	S
<i>Huayro</i>	9.2 b	8883	1.77 c	41.4	9.2	2	S
<i>Canchan</i>	5.60 f	3616	0.72 e	25.2	3.8	1	R
<i>Peruanita</i>	7.57 c	12133	2.42 b	34.1	12.6	2	S
<i>Silver</i>	7.28 c	5566	1.11 d	32.8	5.8	2	R
<i>Imilla negra</i>	5.87 f	11416	2.28 b	26.4	11.9	2	S
<i>Imilla blanca</i>	6.80 d	11516	2.3 b	30.6	12.0	2	S
<i>Florcita</i>	6.39 e	6500	1.3 d	28.8	6.8	2	R
<i>Lomo blanco</i>	5.36 f	4833	0.96 e	24.1	5.0	1	R
<i>Andina</i>	5.68 f	6533	1.3 d	25.6	6.8	2	R
<i>Ccompis</i>	5.36 f	8216	1.64 c	24.1	8.5	2	S
<i>Venturana</i>	6.14 e	7483	1.49 c	27.6	7.8	2	R
<i>Ruki</i>	1 g	0	0 f	4.5	0.0	1	R
CV (%)	6.23	10.5	10.5				
<i>p</i> -value	<0.001	<0.001	<0.001	-	-	-	-

NA: number of galls, NH: number of eggs, RF: reproduction factor (final population / initial population), GI (%): gall index (cultivar nodulations / highest nodulation) $\times 100$, RI (%): reproduction index (cultivar eggs / highest egg count) $\times 100$, R: reaction (Susceptible (RF \geq 1) and Resistant (RF \leq 1)) (Oostenbrink, 1966), RG(1-4): reproduction grade (1(R) RF \leq 1, 2(MR)1<RF \leq 5, 3(S)5<RF \leq 10, and 4(HS)RF>10). CV: coefficient of variation. Means followed by the same letter do not differ significantly from each other according to the Scott-Knott test $p \leq 0.05$.

The cultivars Ccompis and Venturana exhibited notable resistance against *Meloidogyne incognita* and *Meloidogyne arenaria* (RF<1), with values of 0.63, 0.82, 1.08, and 1.75 in assessments I1 and I2 (Tables 1 and 2, respectively); as well as 0.364 and 0.472 in assessment A2 (Table 4). Reproduction indices (RI) were below 6 % (4.4 and 5.7 in I1; 2.8 and 3.7 in A2) (Tables 1 and 4, respectively). Meanwhile, Andina demonstrated high performance against *M. hapla* with RI below 3 % (H1: 0.0; H2: 2.6) (Tables 5 and 6, respectively). Additionally, Huayro exhibited interspecific variability: resistant to *M. arenaria* (A2) with RF=0.87 (Table 4), but susceptible to *M. arenaria* (A1) with RF=9.87 (Table 3). The relationship between galls index (GI) and reproduction index (RI) was not always linear. For instance, Canchán in *M. arenaria* (A1) showed a moderate NI (14.7 %) but a low RI (6.6%) (Table 3), indicating that gall formation does not necessarily reflect the nematode's reproductive capacity.

Finally, the comparison among the evaluated *Meloidogyne* species revealed differences in their capacity for development and reproduction. *M. incognita* (esterase phenotype I2) and *M. arenaria* (esterase phenotype A1) exhibited faster population development, suggesting greater aggressiveness and infection capacity in potato crops. In contrast, *M. hapla* (esterase phenotypes H1 and H2) showed a slower growth dynamics, indicating a lower reproductive potential under the experimental conditions evaluated. Likewise, *M. arenaria* (esterase phenotype A2) showed a relatively stable behavior compared with the other species, without a significant initial increase in population development, suggesting a potentially lower impact on potato cultivation.

The results of this study support the hypothesis that resistance to *Meloidogyne* spp. in potato is largely dependent on the cultivar-species interaction. The resistance observed in Ruki compared to other varieties suggests the presence of a broad resistance mechanism, possibly associated with R genes such as Mi-1, as confirmed by Williamson and Kumar (2006) and

Spychalla and De Jong (2024). However, the susceptibility of cultivars like Silver (moderately resistant to *M. incognita* but resistant to *M. arenaria*) indicates that these mechanisms may be species-specific (Goverse and Geert, 2006).

The high variability in the coefficients of variation (CV) for eggs/RF (16.66-67.27 %) suggests that environmental or epigenetic factors may modulate the response, as reported by Sikora *et al.* (2018). The discrepancy between % IN and % IR in cultivars like Peruanita (high % IN but low RF) raises questions about the effectiveness of using gall visual assessments as the sole resistance criterion, supporting the need to integrate molecular PCR methods (Spychalla and De Jong, 2024).

The susceptibility of cultivars such as Silver (moderately resistant to *M. incognita* but resistant to *M. arenaria*) indicates that resistance mechanisms may be species-specific (Chang *et al.*, 2014). The results obtained in this study show clear alignment with previous research related to the resistance and susceptibility of potato varieties to *Meloidogyne* spp. However, there are discrepancies in the categorization of cultivars with intermediate resistance; for example, Peruanita has been classified as resistant in some studies, while our data place it in the moderately resistant category. Additionally, cases such as Silver were identified, exhibiting a moderate nodulation index but high reproduction, a relationship not consistently reported in the literature and highlighting the importance of considering multiple parameters for a comprehensive evaluation (Jones *et al.*, 2013).

The triad composed of reproduction factor (RF), galls index (GI), and reproduction index (RI) provides a comprehensive assessment of resistance. For example, Imilla Blanca, with RF=0.94, NI=21.3 %, and RI=7.0 %, meets all resistance criteria, whereas Florcita, with RF=1.63, NI=29.2 %, and RI=12.1 %, is classified as moderately resistant. These results are consistent with the conclusions of Ali *et al.* (2017), who emphasized that durable resistance requires low GI and RI percentages, as demonstrated in cultivars such as Ruki and Andina. These findings support integrated breeding strategies aimed at both preventing nematode penetration and activating post-infection

defenses to develop nematode-resistant potato varieties.

CONCLUSION

Among the potato varieties analyzed, Ruki stands out as the most resistant to *Meloidogyne* spp., exhibiting the lowest incidence. In contrast, Yungay was identified as the most susceptible to *Meloidogyne* spp. populations. Other varieties such as Ccompis, Venturana, and Imillas display moderate resistance, while Huayro, Canchán, and Silver exhibit higher susceptibility.

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